Unit 1
Biochemistry

Chapter 3: Carbon and the Molecular Diversity of Life

Overview: Carbon Compounds and Life

- Aside from water, living organisms consist mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- A compound containing carbon chains is said to be an **organic compound**

- Critically important molecules of all living things fall into four main classes
  - Carbohydrates
  - Nucleic Acids
  - Proteins
  - Lipids
- The first three of these can form huge molecules called **macromolecules**
- Large biological molecules exhibit unique *emergent properties* arising from the orderly arrangement of their atoms

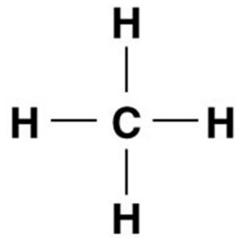
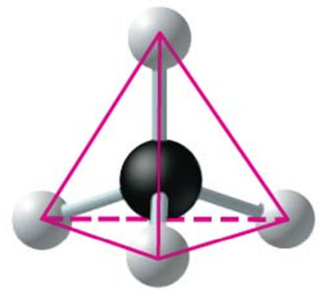
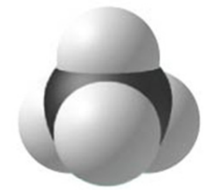
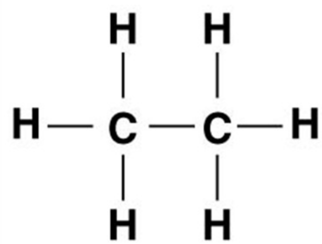
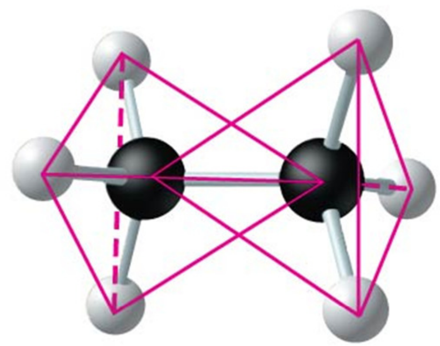
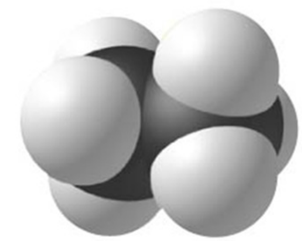
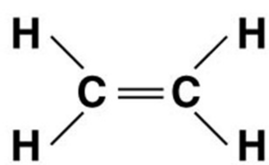
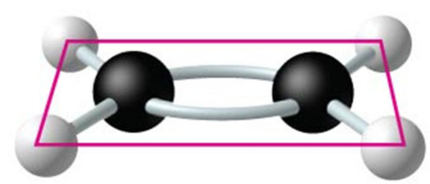
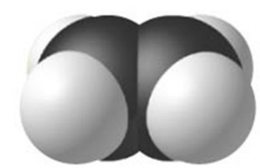
Concept 3.1: Carbon atoms can form diverse molecules by bonding to four other atoms

- An atom's electron configuration determines the kinds and number of bonds the atom will form with other atoms
- This is the source of carbon's versatility

The Formation of Bonds with Carbon

- With four **valence** electrons, carbon can form four covalent bonds with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double bond, the atoms joined to the carbons are in the same plane as the carbons

Figure 3.2

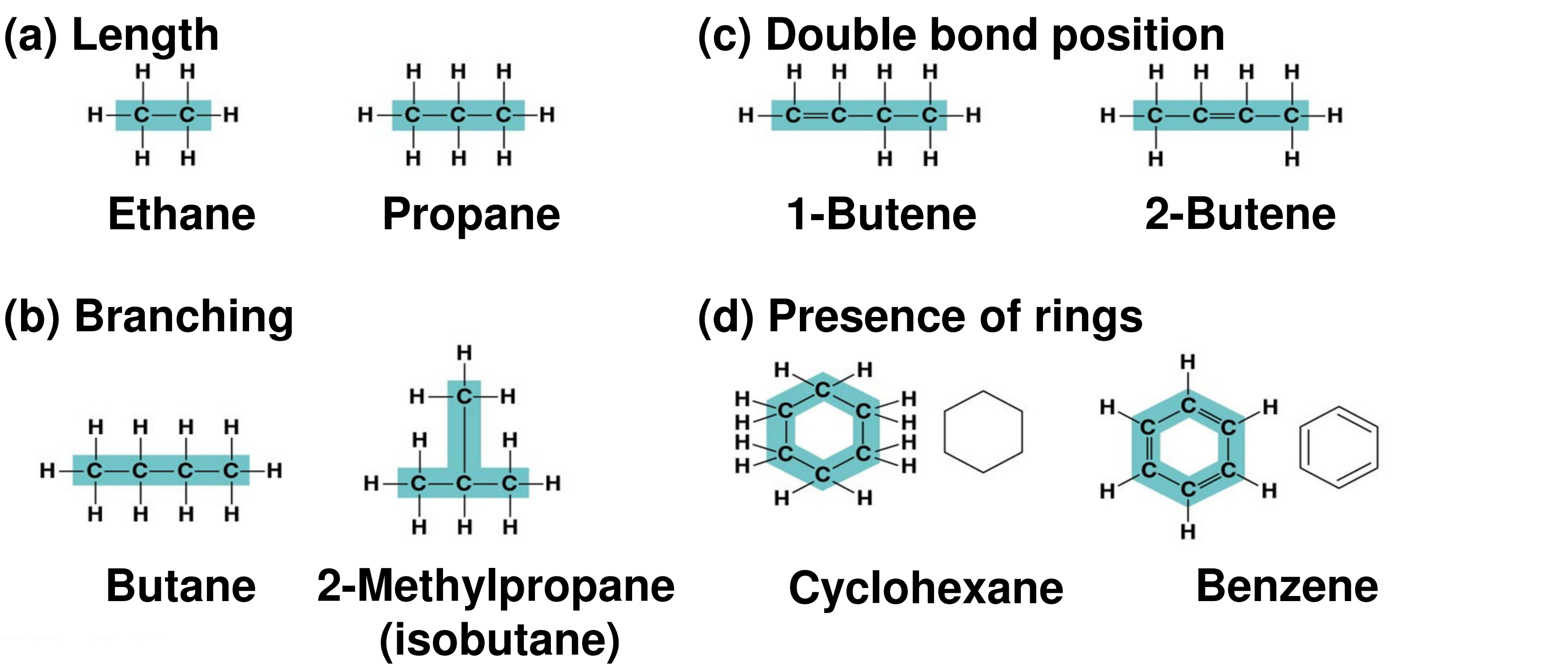
Name	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
Methane				
Ethane				
Ethene (ethylene)				

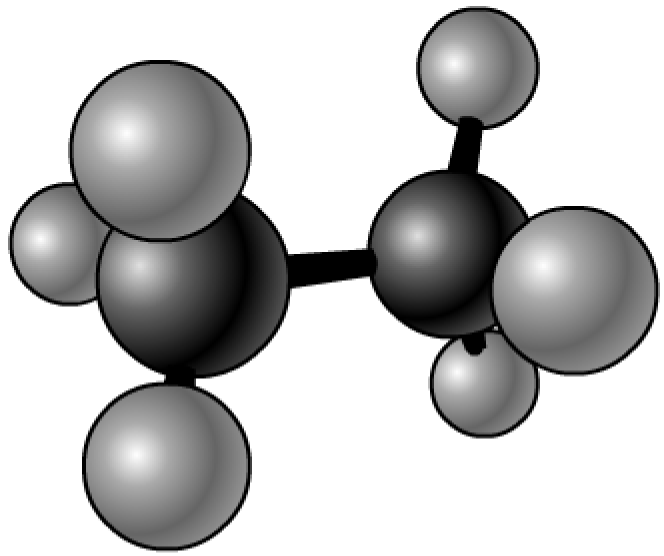
- The electron configuration of carbon gives it covalent compatibility with many different elements
- The valences of carbon and its most frequent partners (hydrogen, oxygen, and nitrogen) are the "building code" that governs the architecture of living molecules

Hydrogen (valence = 1) | **Oxygen (valence = 2)** | **Nitrogen (valence = 3)** | **Carbon (valence = 4)**

Molecular Diversity Arising from Variation in Carbon Skeletons

- Carbon chains form the skeletons of most organic molecules
- Carbon chains vary in length and shape
  - This variation is one important source of the molecular complexity and diversity of living things





Animation: Carbon Skeletons
Right click slide / Select play

- **Hydrocarbons** are organic molecules consisting of only carbon and hydrogen
- Many organic molecules, such as fats, have hydrocarbon components
- Characteristics of Hydrocarbons
  - Hydrophobic
  - Can undergo reactions that release a large amount of energy

The Chemical Groups Most Important to Life

- **Functional groups** are the components of organic molecules that are most commonly involved in chemical reactions
- The number and arrangement of functional groups give each molecule its unique properties

- The seven functional groups that are most important in the chemistry of life:
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group
  - Methyl group

Figure 3.5a

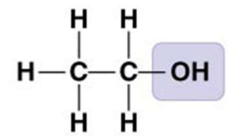
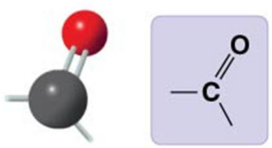
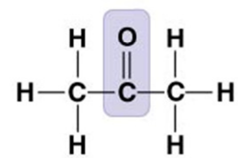
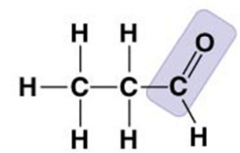
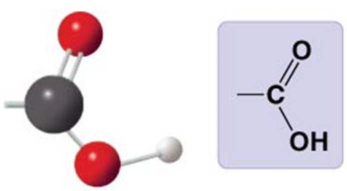
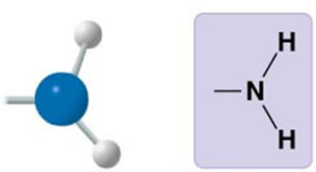
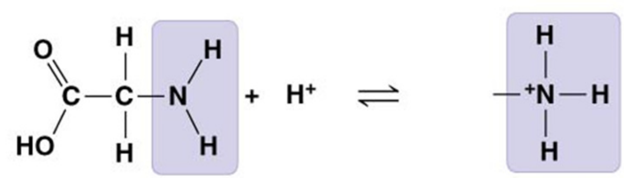
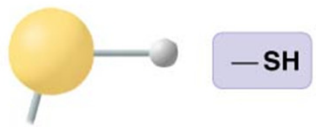
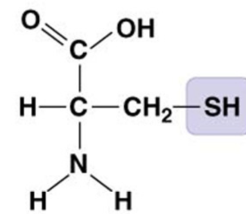
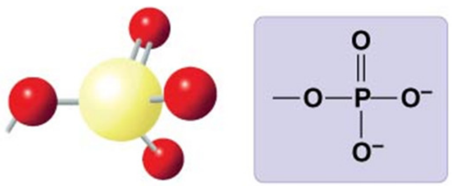
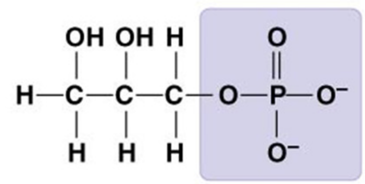
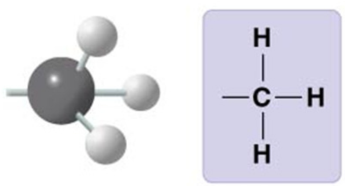
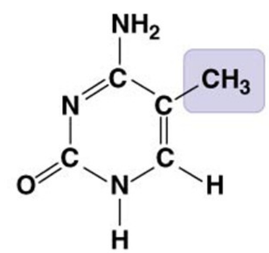
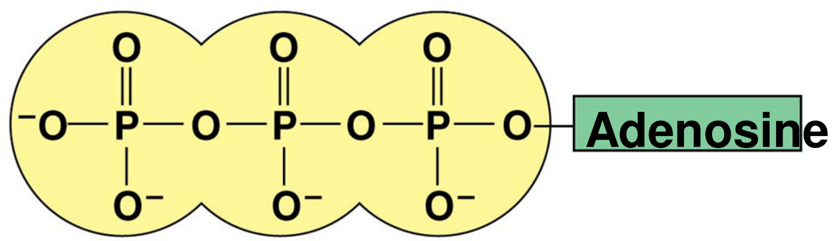
Chemical Group	Compound Name	Examples
Hydroxyl group (—OH) 	**Alcohol**	 **Ethanol**
Carbonyl group (>C=O) 	**Ketone** **Aldehyde**	 **Acetone**  **Propanal**
Carboxyl group (—COOH) 	**Carboxylic acid, or organic acid**	 **Acetic acid**
Amino group (—NH$_2$) 	**Amine**	 **Glycine**

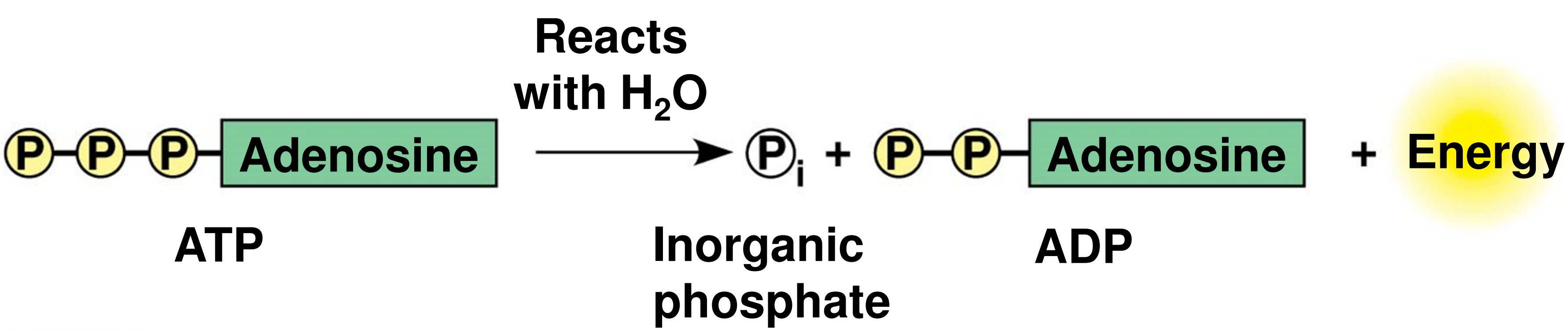
Figure 3.5b

Chemical Group	Compound Name	Examples
Sulfhydryl group (—SH) 	**Thiol**	 **Cysteine**
Phosphate group (— OPO_3^{2-}) 	**Organic phosphate**	 **Glycerol phosphate**
Methyl group (— CH_3) 	**Methylated compound**	 **5-Methyl cytosine**

ATP: An Important Source of Energy for Cellular Processes

- One organic phosphate molecule, **adenosine triphosphate** (**ATP**), is the primary energy-transferring molecule in the cell
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups



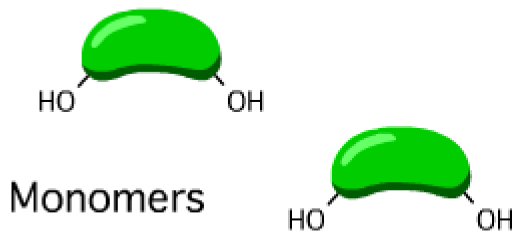


Concept 3.2: Macromolecules are polymers, built from monomers

- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**

The Synthesis and Breakdown of Polymers

- **Dehydration reaction =**
  - *Joins* monomers together into polymers through the *loss* of a water molecule
- **Hydrolysis** =
  - *Disassembles* polymers into to monomers through the *addition* of water
  - Ex: Digestion
- These processes are facilitated by **enzymes**, which speed up chemical reactions



Animation: Polymers
Right click slide / Select play

Figure 3.6a

(a) Dehydration reaction: synthesizing a polymer

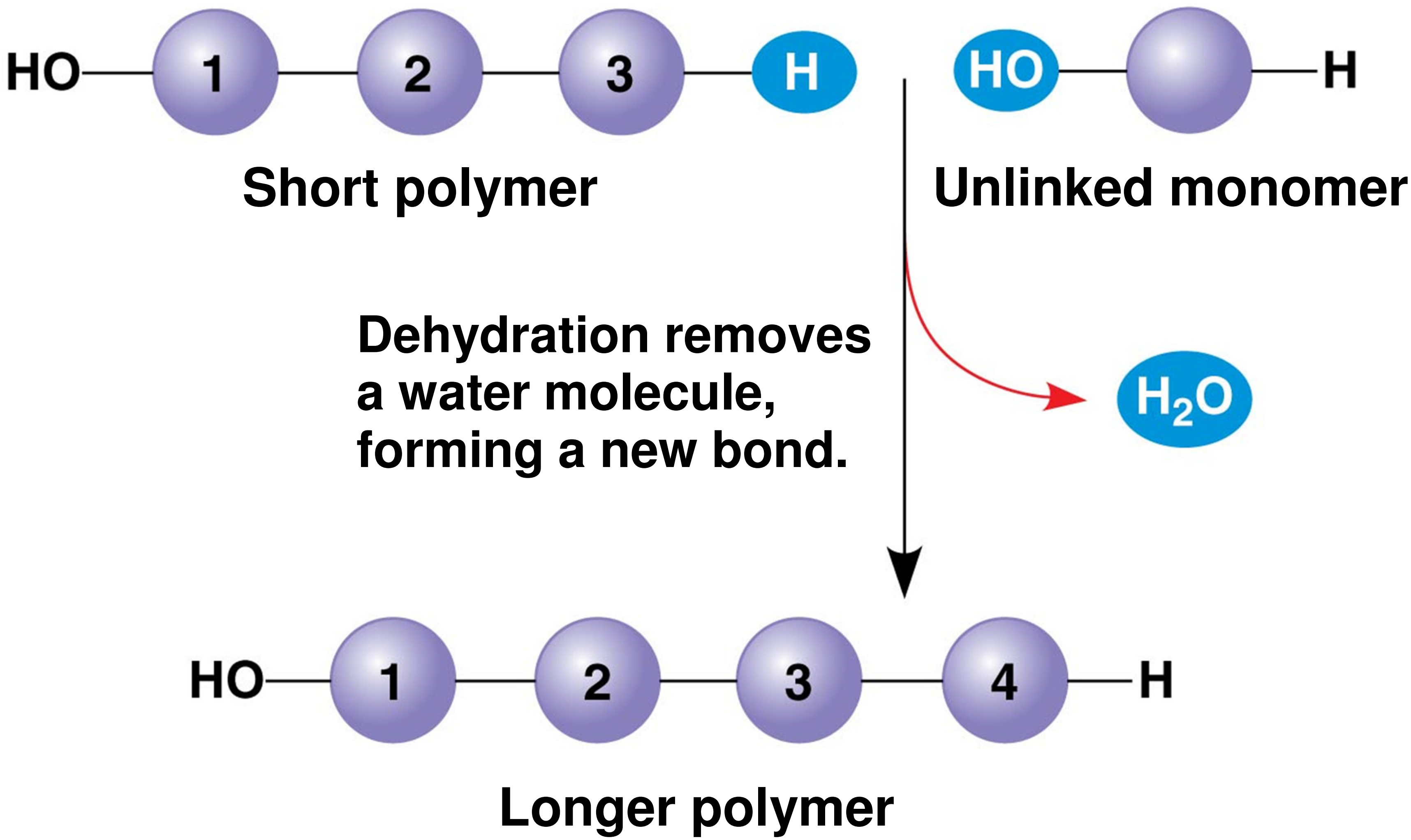
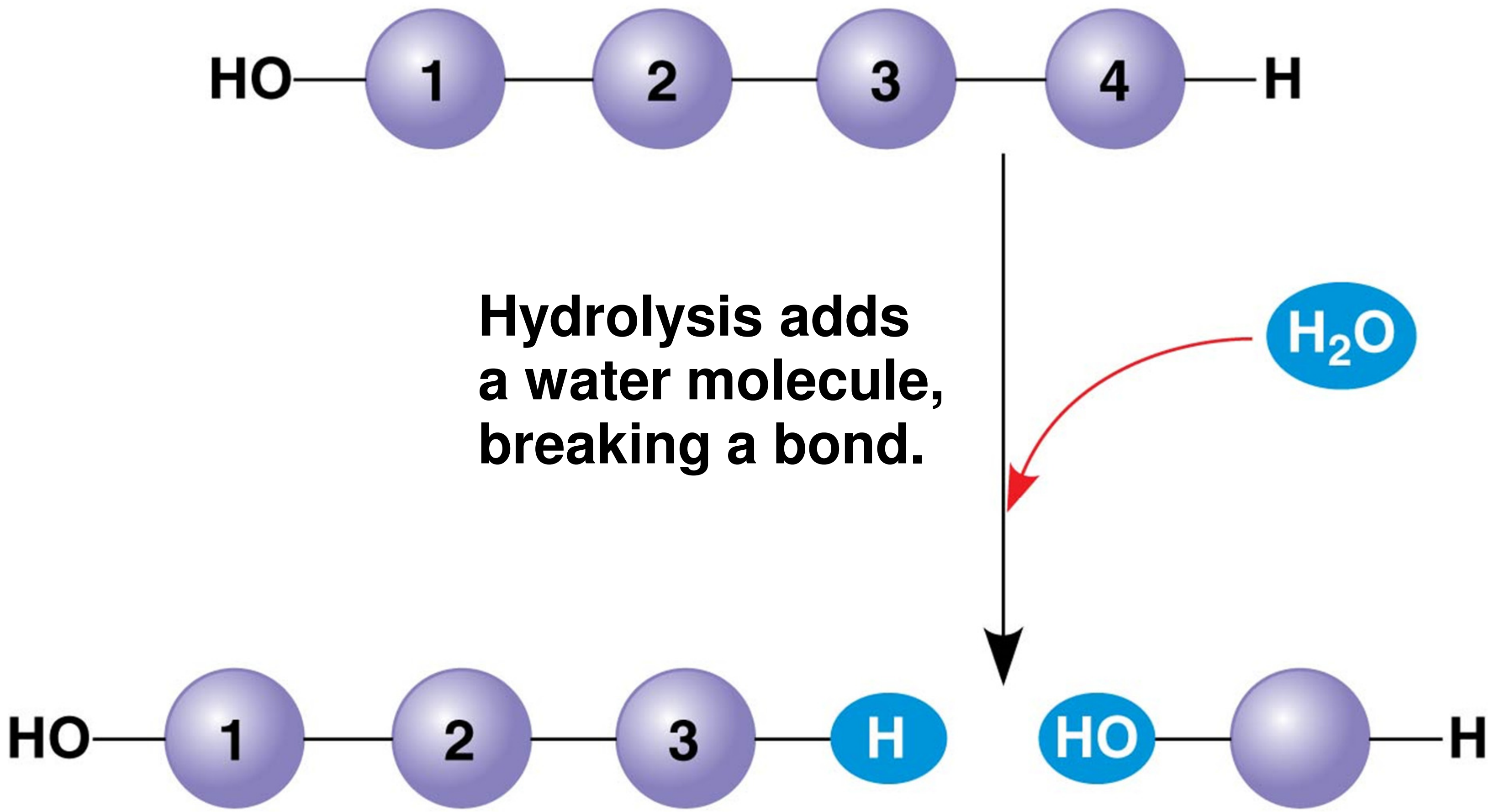


Figure 3.6b

(b) Hydrolysis: breaking down a polymer



The Diversity of Polymers

- Each cell has thousands of different macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- An immense variety of polymers can be built from a small set of monomers
  - The key is arrangement
- Large molecules have *emergent* properties not found in their individual building blocks.

Macromolecule/ Polymer	Monomer	Function
Carbohydrates (Polysaccharides) Ex: Starch, Cellulose	Monosaccharides (simple sugars) Ex: Glucose	Energy
Lipids Ex: Fats, Oils, Waxes, Phospholipids,Steroids	Glycerol and Fatty acids	Energy Pad, Insulate Cell Membranes
Nucleic Acids Ex: DNA and RNA	Nucleotides	Heredity Protein Synthesis
Proteins/ Polypeptides	Amino Acids	Enzymes, Antibodies, Transportation, Storage, Movement, Repair/Maintenance, Hormones, Signaling

Concept 3.3: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or simple sugars
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks

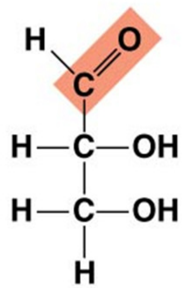
Sugars

- **Monosaccharides** serve as a major *fuel* for cells and as *raw material* for building molecules
- Monosaccharides have molecular formulas that are usually multiples of CH_2O
  - Glucose ($C_6H_{12}O_6$) is the most common monosaccharide

- Monosaccharides are classified by
  - The number of carbons in the carbon skeleton
    - Hex<u>ose</u> (6); Pent<u>ose</u> (5); Tri<u>ose</u> (3)
  - The placement of the carbonyl group (C=O)
    - *Ketone* if carbonyl group is within carbon skeleton
    - *Aldehyde* if carbonyl group is at end
- They also have multiple hydroxyl groups (-OH)
- Though often drawn as linear skeletons, in aqueous solutions many sugars form rings

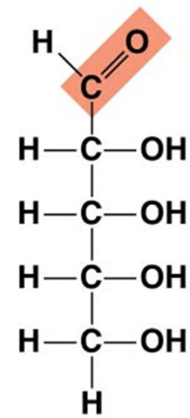
Figure 3.7

Triose: 3-carbon sugar ($C_3H_6O_3$)



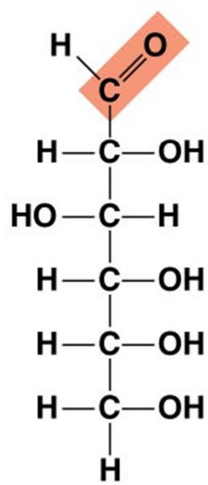
Glyceraldehyde
An initial breakdown product of glucose in cells

Pentose: 5-carbon sugar ($C_5H_{10}O_5$)

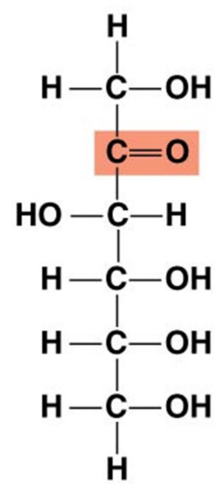


Ribose
A component of RNA

Hexoses: 6-carbon sugars ($C_6H_{12}O_6$)



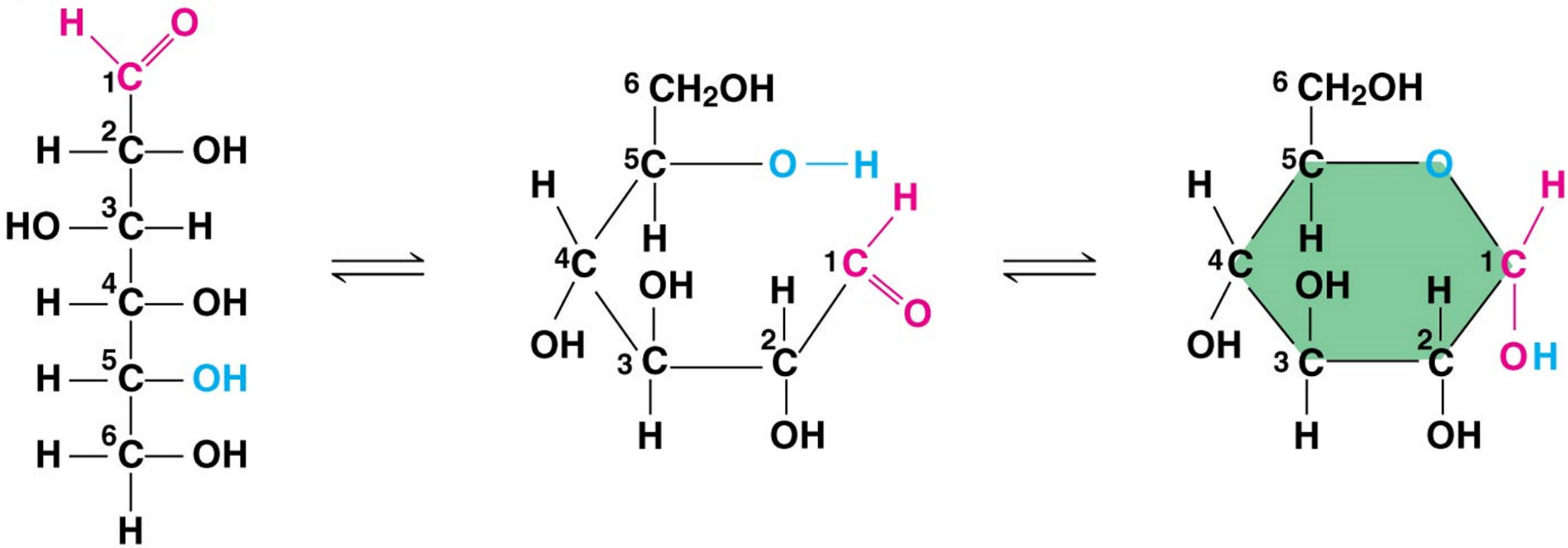
Glucose



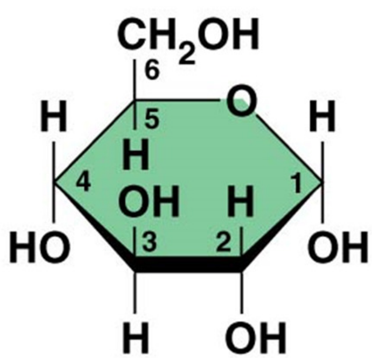
Fructose

Energy sources for organisms

Figure 3.8

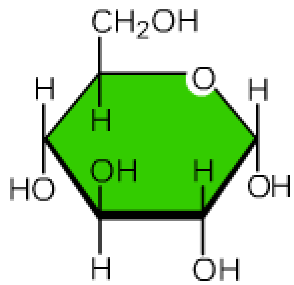


(a) Linear and ring forms

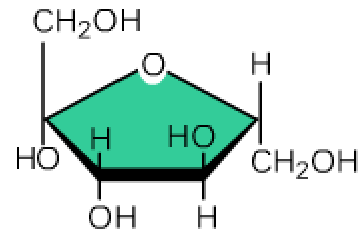


(b) Abbreviated ring structure

- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**
- Most common disaccharide is sucrose



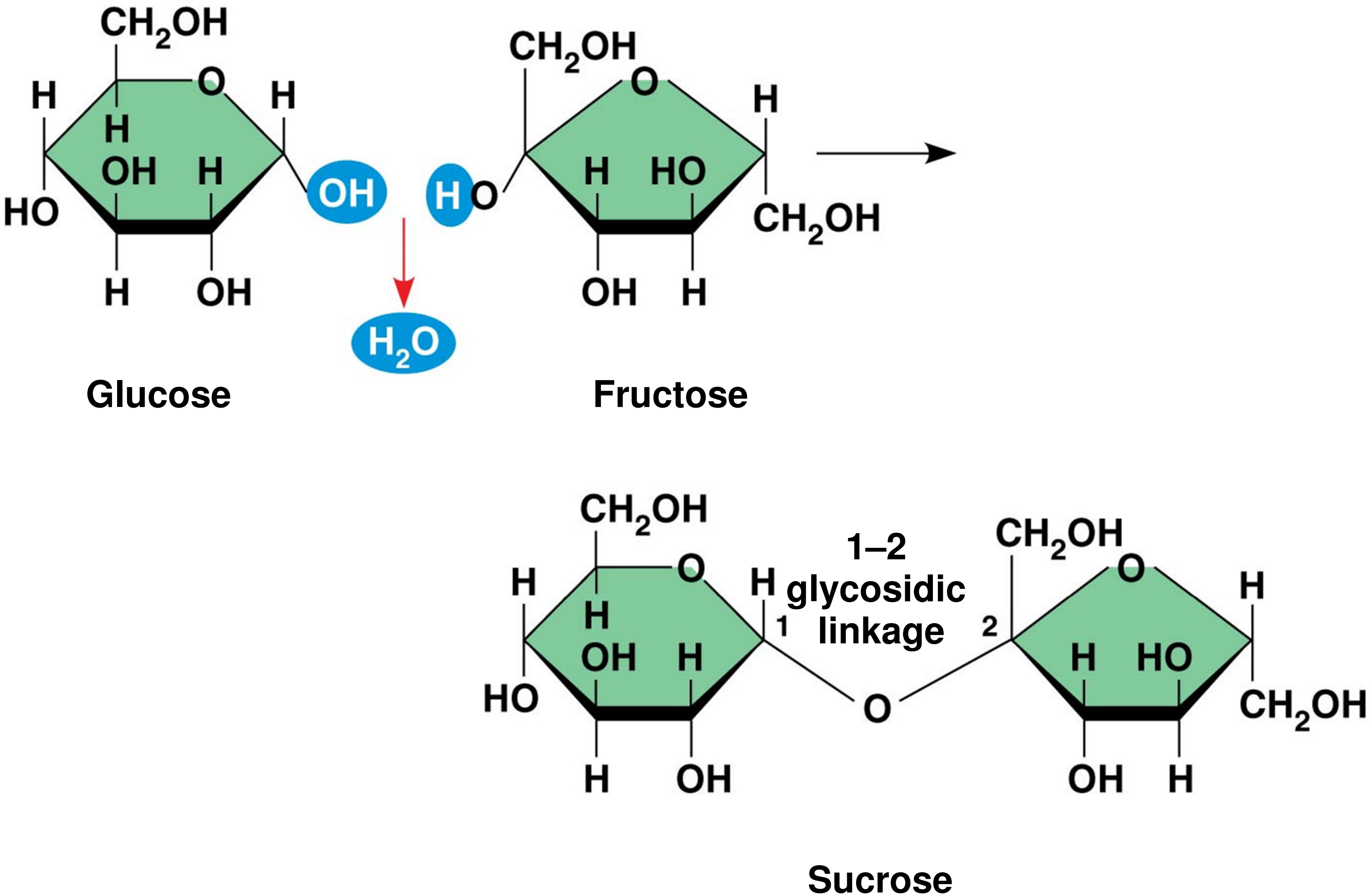
Glucose



Fructose

Animation: Disaccharides
Right click slide / Select play

Figure 3.9-2



CH₂OH
H
OH
HO
Glucose
Fructose
H_2O
1–2 glycosidic linkage
1
2
O
Sucrose

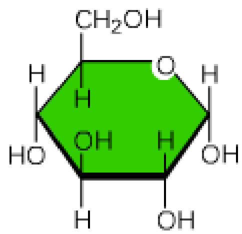
Polysaccharides

- **Polysaccharides**, the polymers of sugars, have *storage and structural* roles
- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages

Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules
- The simplest form of starch is amylose

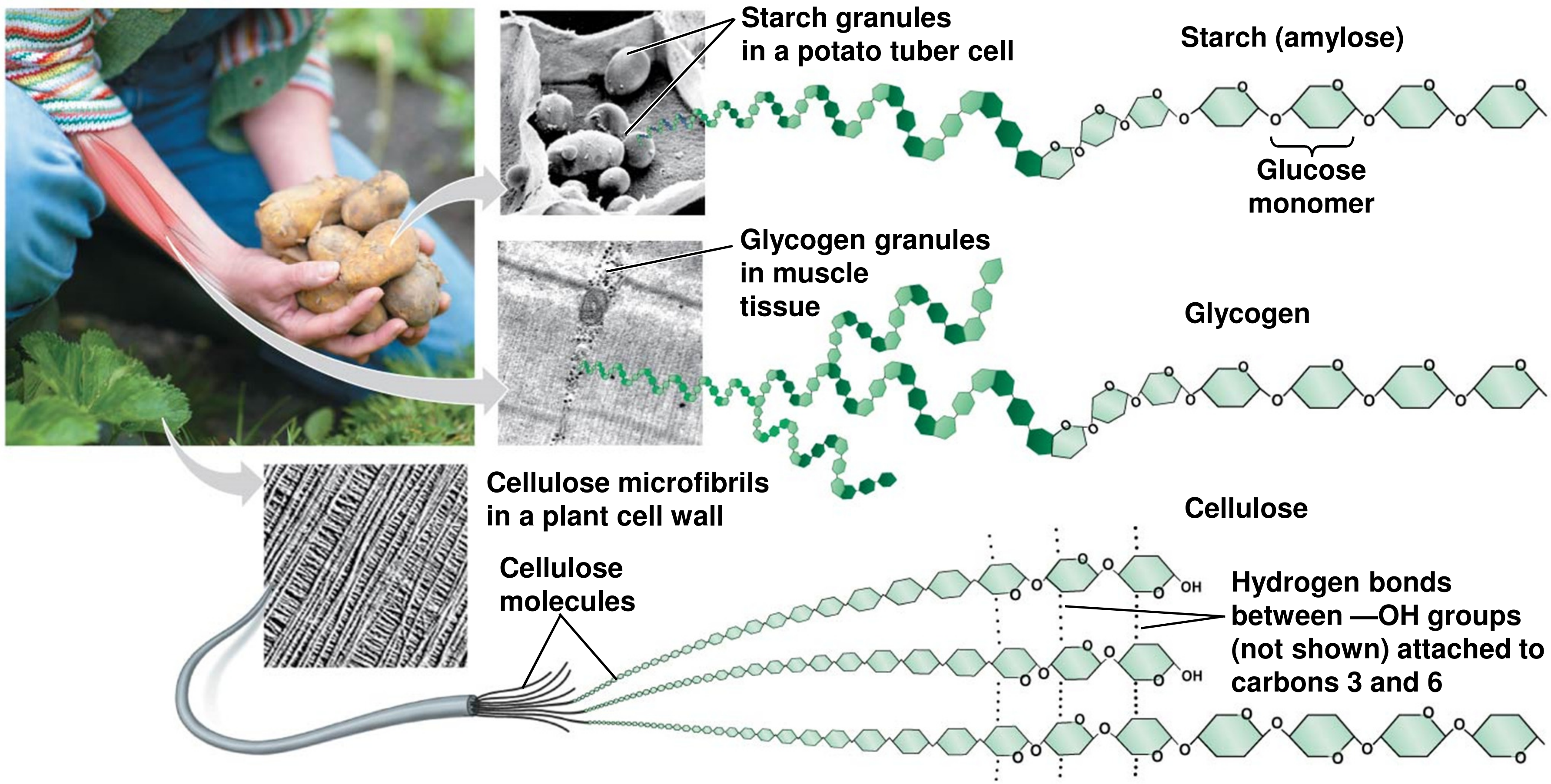
- **Glycogen** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells
  - Hydrolysis of glycogen in these cells releases glucose when the demand for sugar increases



Animation: Polysaccharides

Right click slide / Select play

Figure 3.10

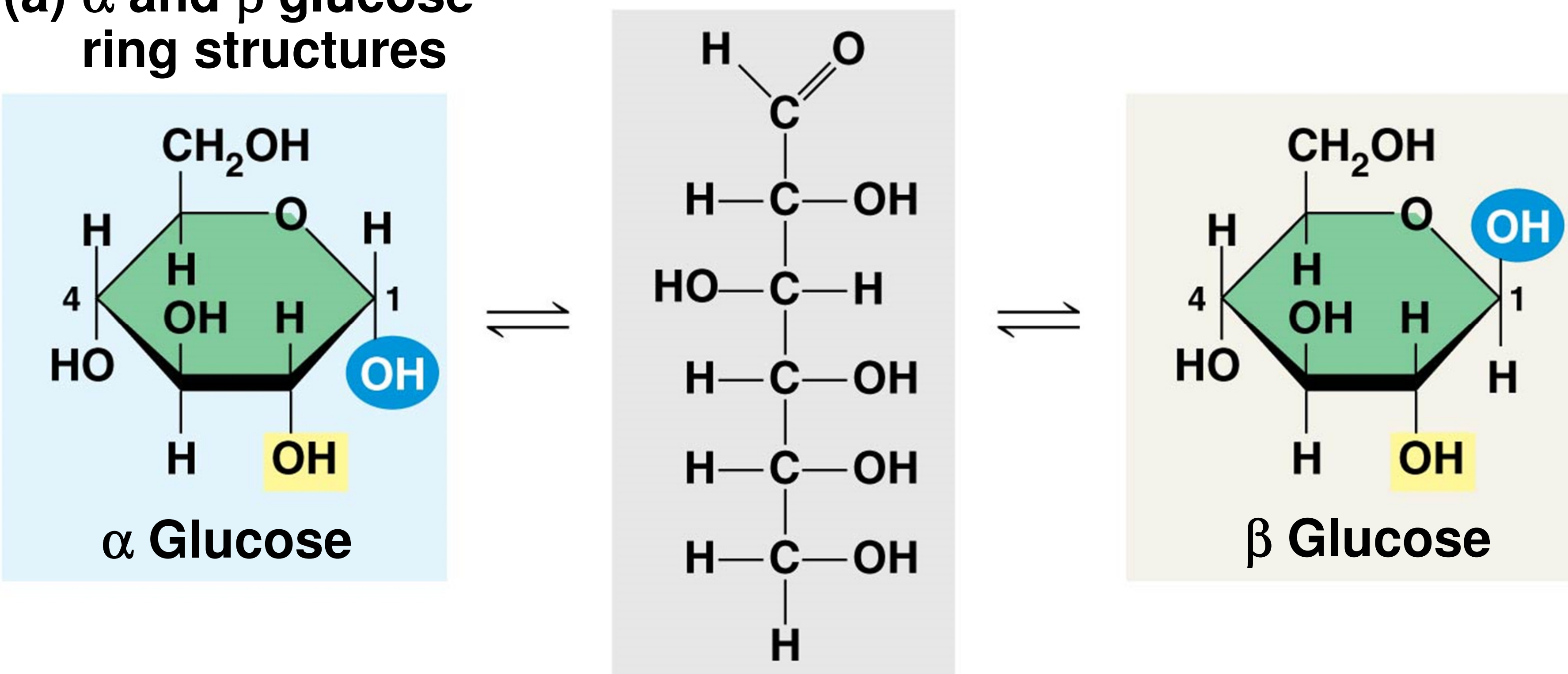

Starch granules
in a potato tuber cell
Starch (amylose)
Glucose
monomer
Glycogen granules
in muscle
tissue
Glycogen
Cellulose microfibrils
in a plant cell wall
Cellulose
Cellulose
molecules
Hydrogen bonds
between —OH groups
(not shown) attached to
carbons 3 and 6

Structural Polysaccharides

- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch and glycogen, cellulose is a polymer of glucose, but the glycosidic linkages in cellulose differ
- The difference is based on two ring forms for glucose (α or β)

Figure 3.11a

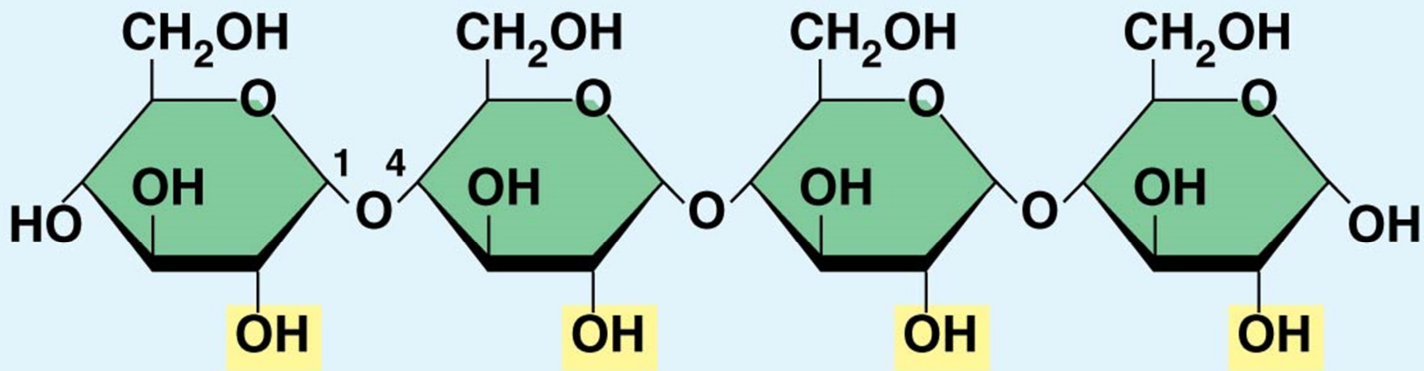
(a) α and β glucose ring structures



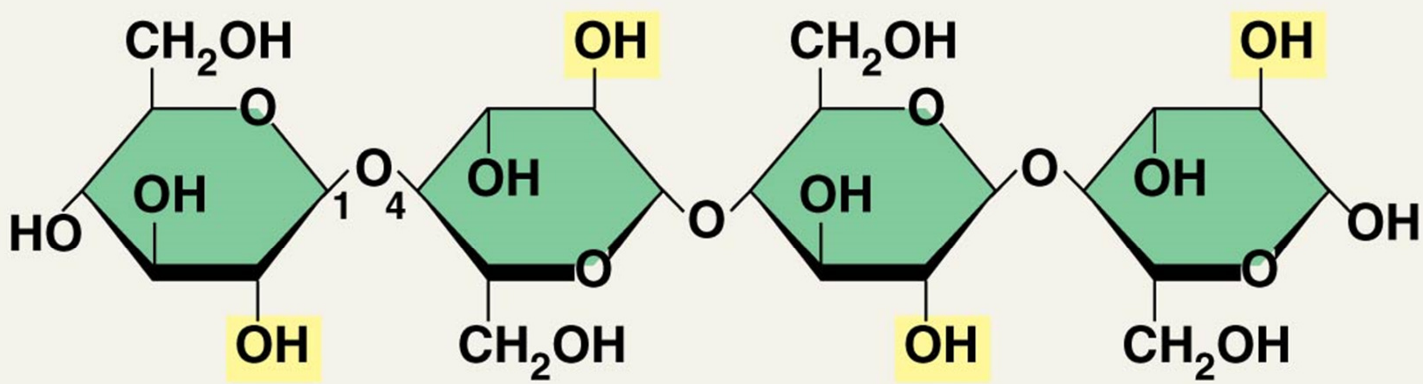
- In starch, the glucose monomers are arranged in the alpha (α) conformation
- Starch (and glycogen) are largely helical

- In cellulose, the monomers are arranged in the beta (β) conformation
- Cellulose molecules are relatively straight

Figure 3.11b



(b) Starch: 1–4 linkage of α glucose monomers



(c) Cellulose: 1–4 linkage of β glucose monomers

- In straight structures (cellulose), H atoms on one strand can form hydrogen bonds with OH groups on other strands
- Parallel cellulose molecules held together this way are grouped into microfibrils, which form strong building materials for plants

- Enzymes that digest starch by hydrolyzing α linkages can't hydrolyze β linkages in cellulose
  - Due to different shapes!
- Cellulose in human food passes through the digestive tract as insoluble fiber
  - We can't digest it!
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

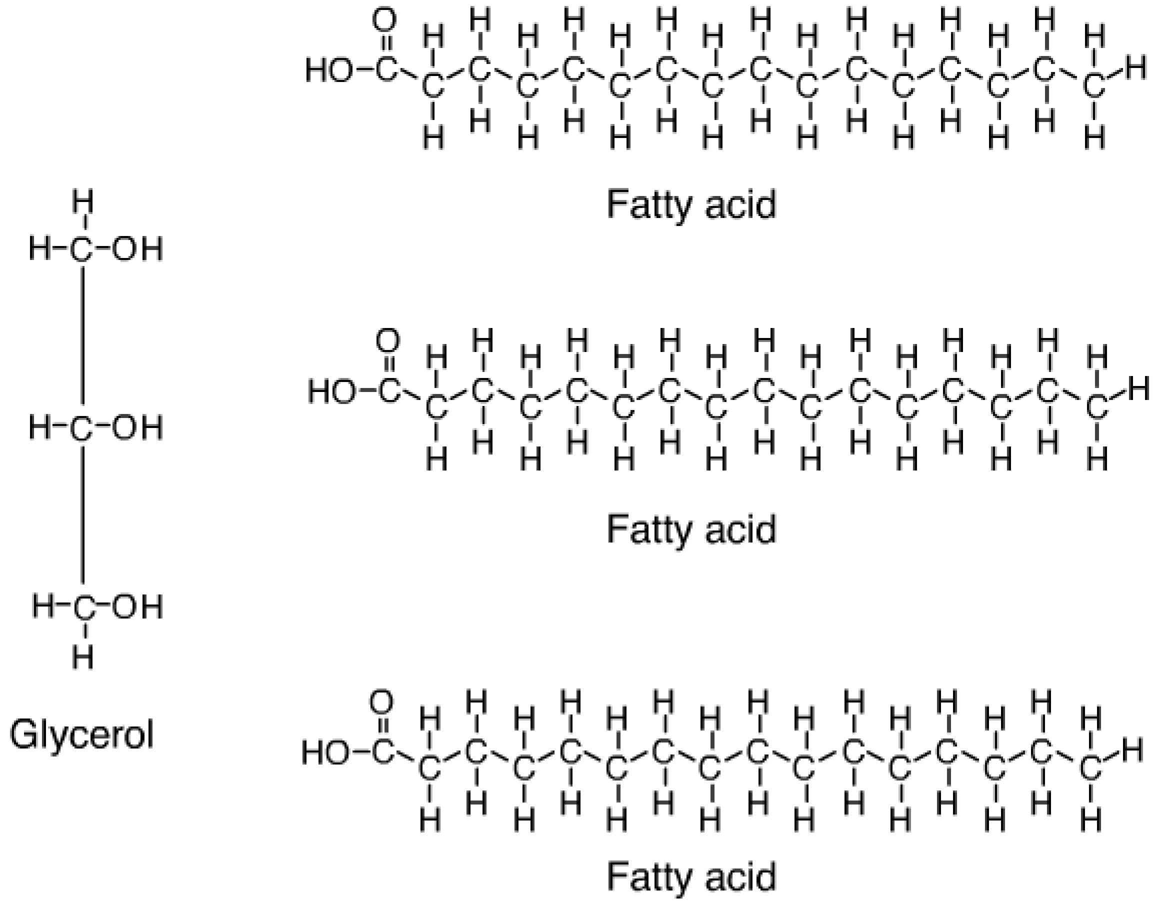
- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

Concept 3.4: Lipids are a diverse group of hydrophobic molecules

- **Lipids** do not form true polymers
- The unifying feature of lipids is having little or no affinity for water
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds
- The most biologically important lipids are fats, phospholipids, and steroids

Fats

- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton
- Fats separate from water because water molecules hydrogen-bond to each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride



Animation: Fats

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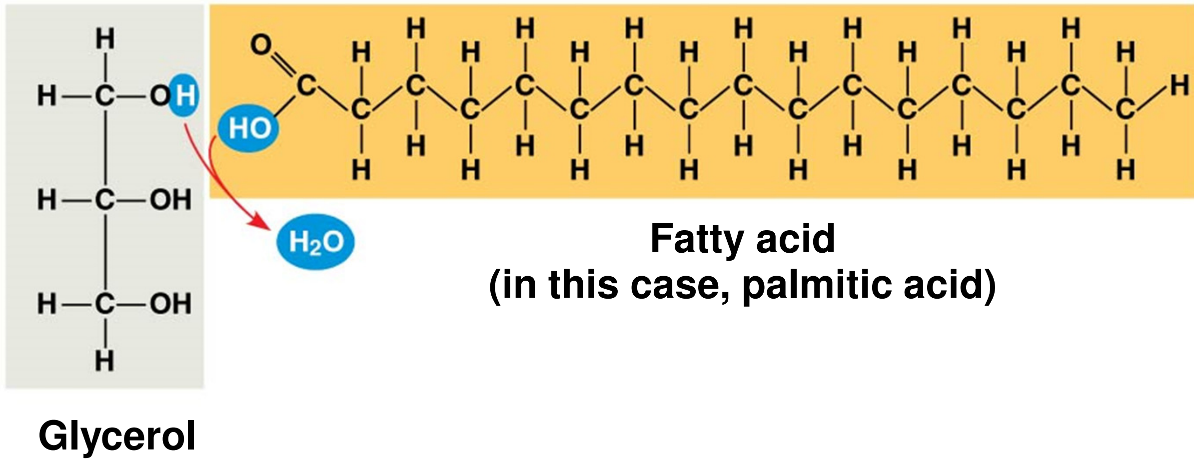
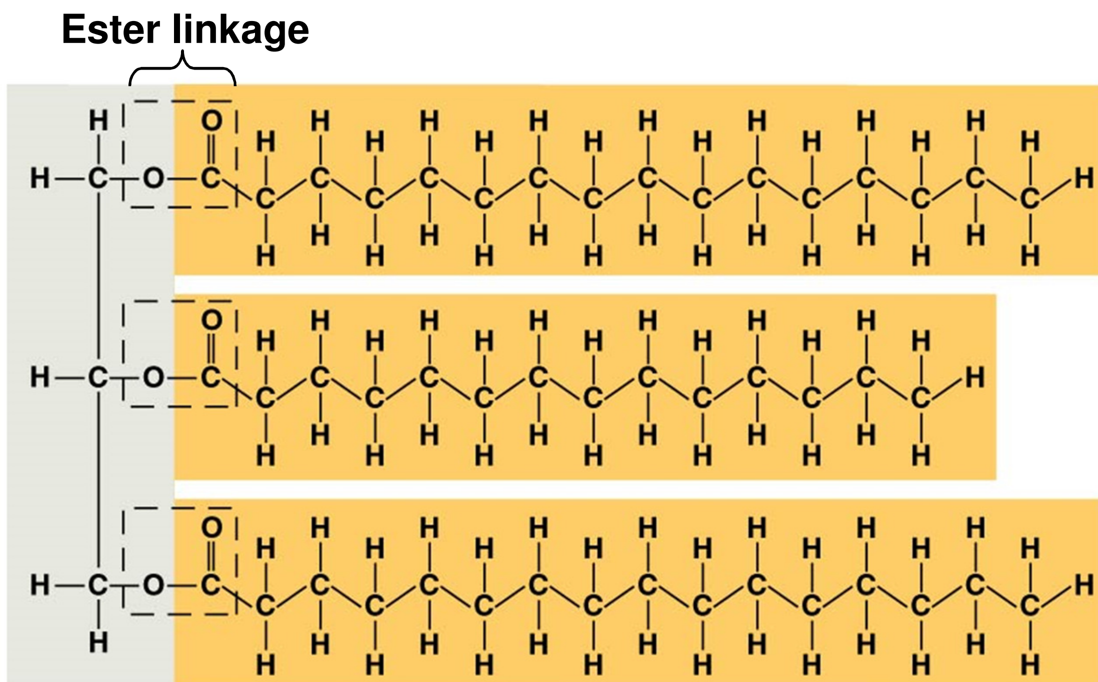
Figure 3.12



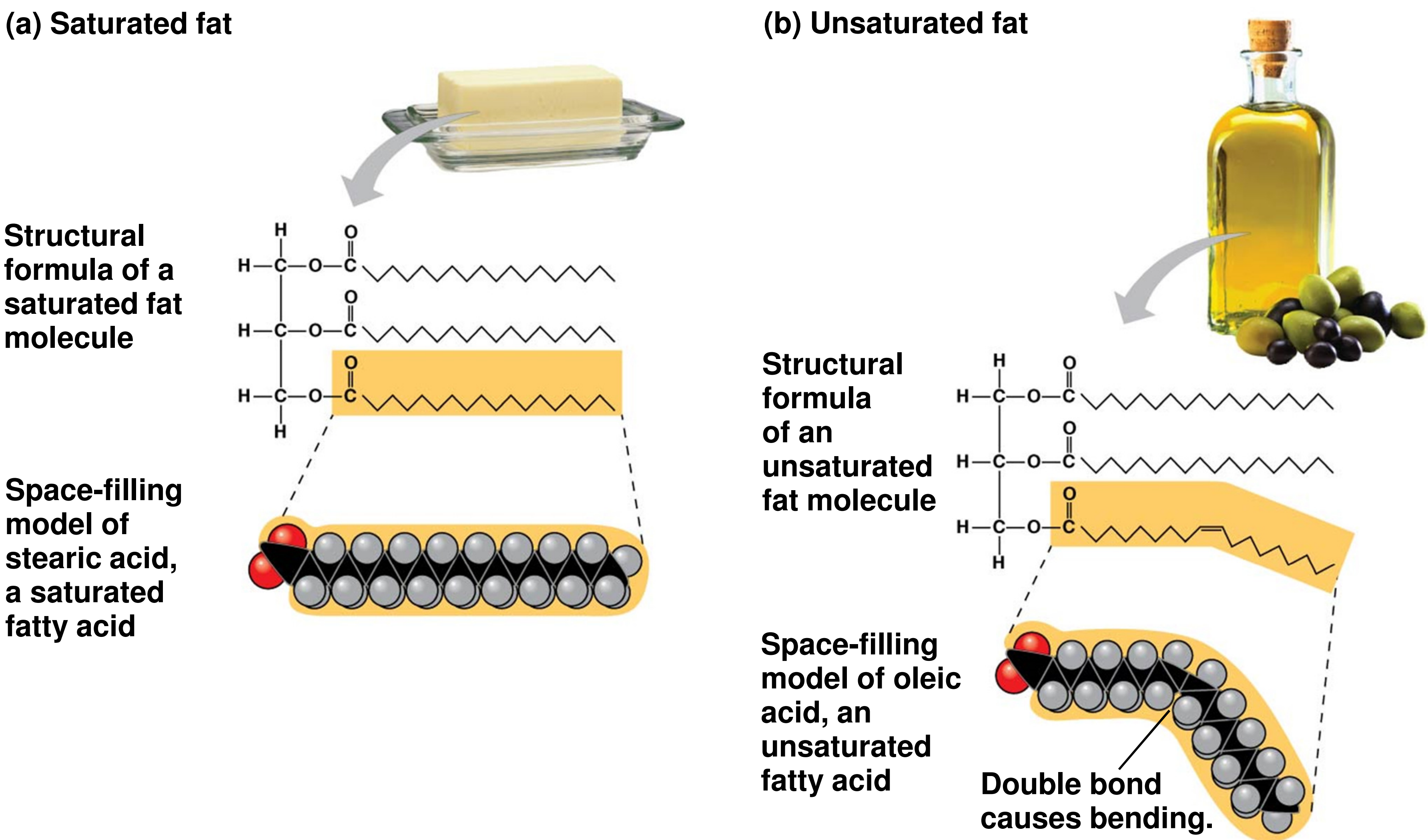
(a) One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
  - **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
    - Solid at room temperature
    - Most animal fats
  - **Unsaturated fatty acids** have one or more double bonds
    - Creates “kinks” in hydrocarbon chain
    - Usually liquid at room temperature
    - Oils-Plant and fish fats

Figure 3.13

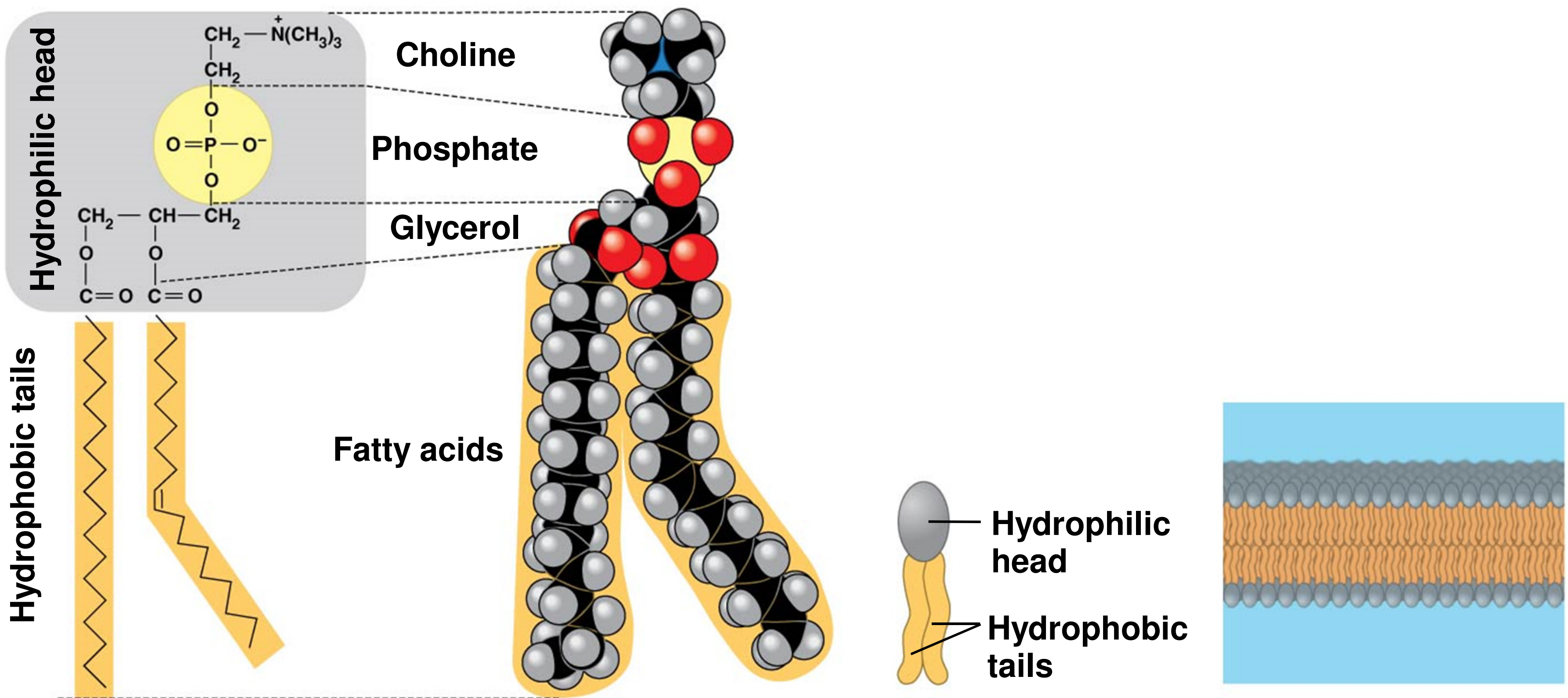

(a) Saturated fat
Structural formula of a saturated fat molecule
Space-filling model of stearic acid, a saturated fatty acid
(b) Unsaturated fat
Structural formula of an unsaturated fat molecule
Space-filling model of oleic acid, an unsaturated fatty acid
Double bond causes bending.

- The major function of fats is *energy storage*
- Fat is a compact way for animals to carry their energy stores with them

Phospholipids

- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head
- When phospholipids are added to water, they self-assemble into a bilayer, with the hydrophobic tails pointing toward the interior
  - This feature of phospholipids results in the bilayer arrangement found in *<u>cell membranes</u>*

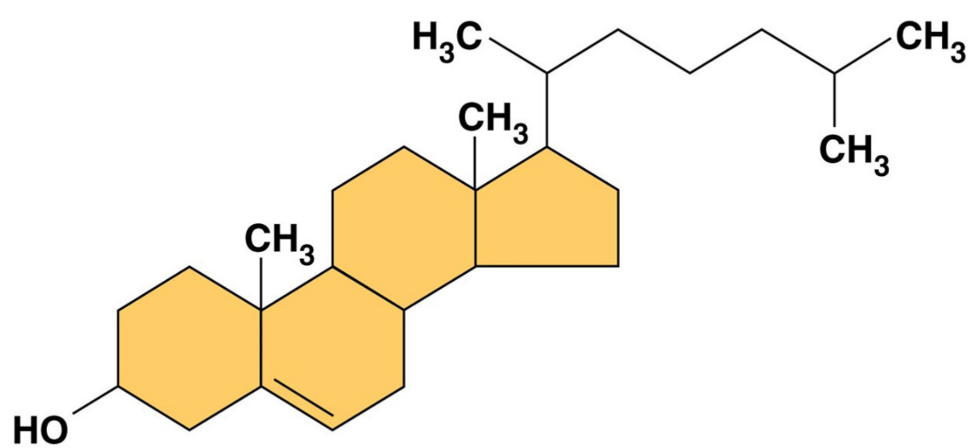
Figure 3.14

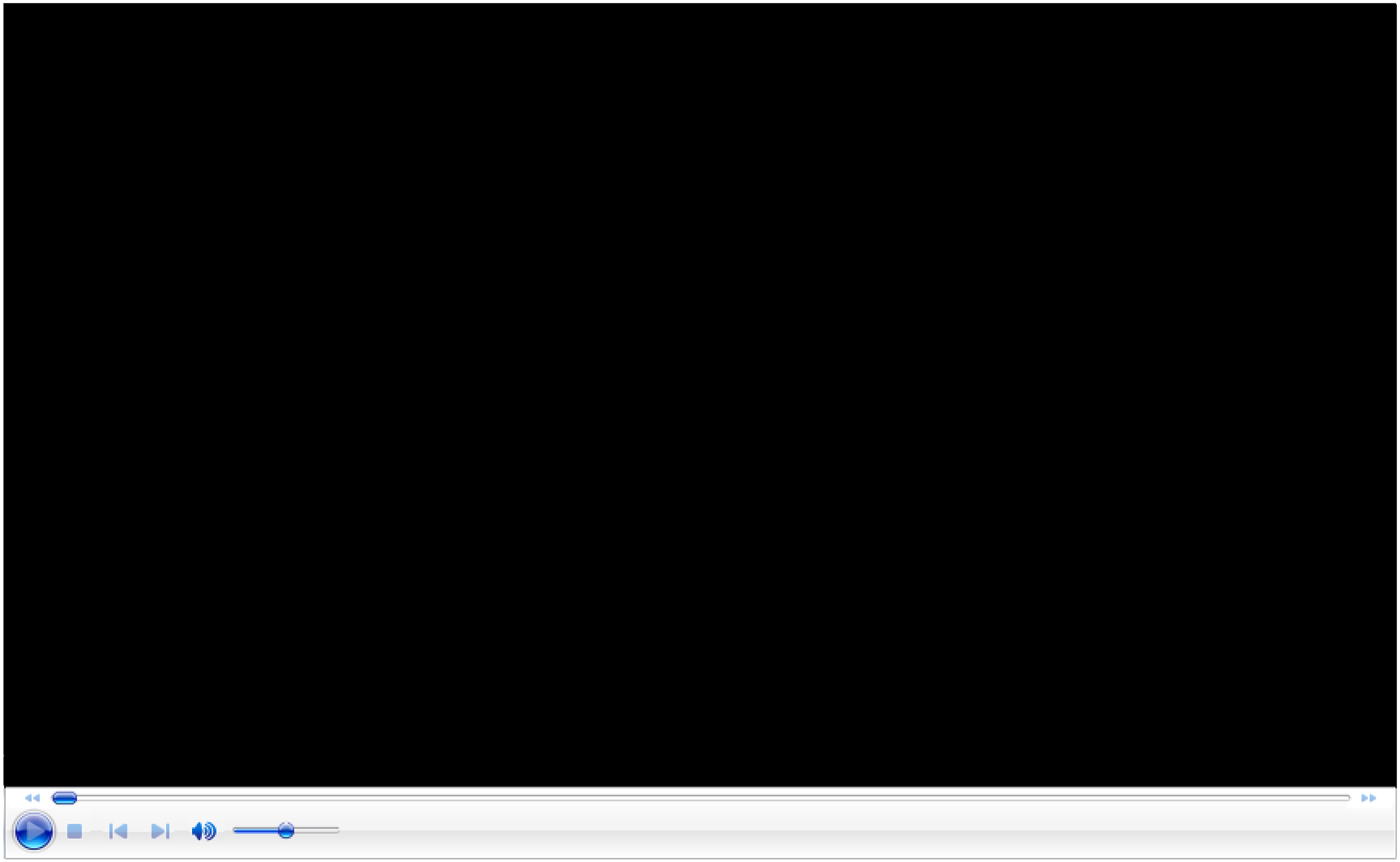


(a) Structural formula (b) Space-filling model (c) Phospholipid symbol (d) Phospholipid bilayer

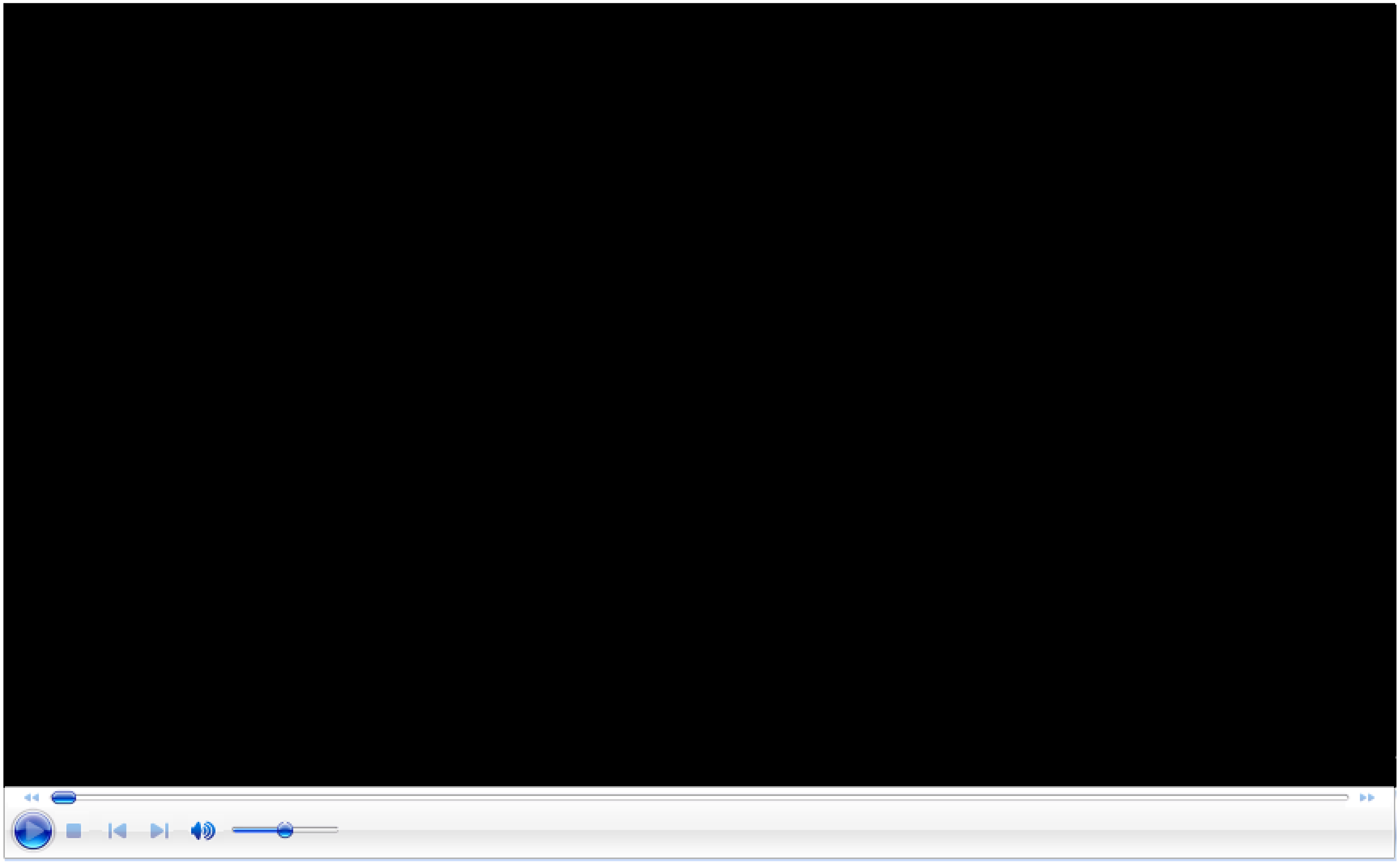
Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, an important steroid, is a component in animal cell membranes
- Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease





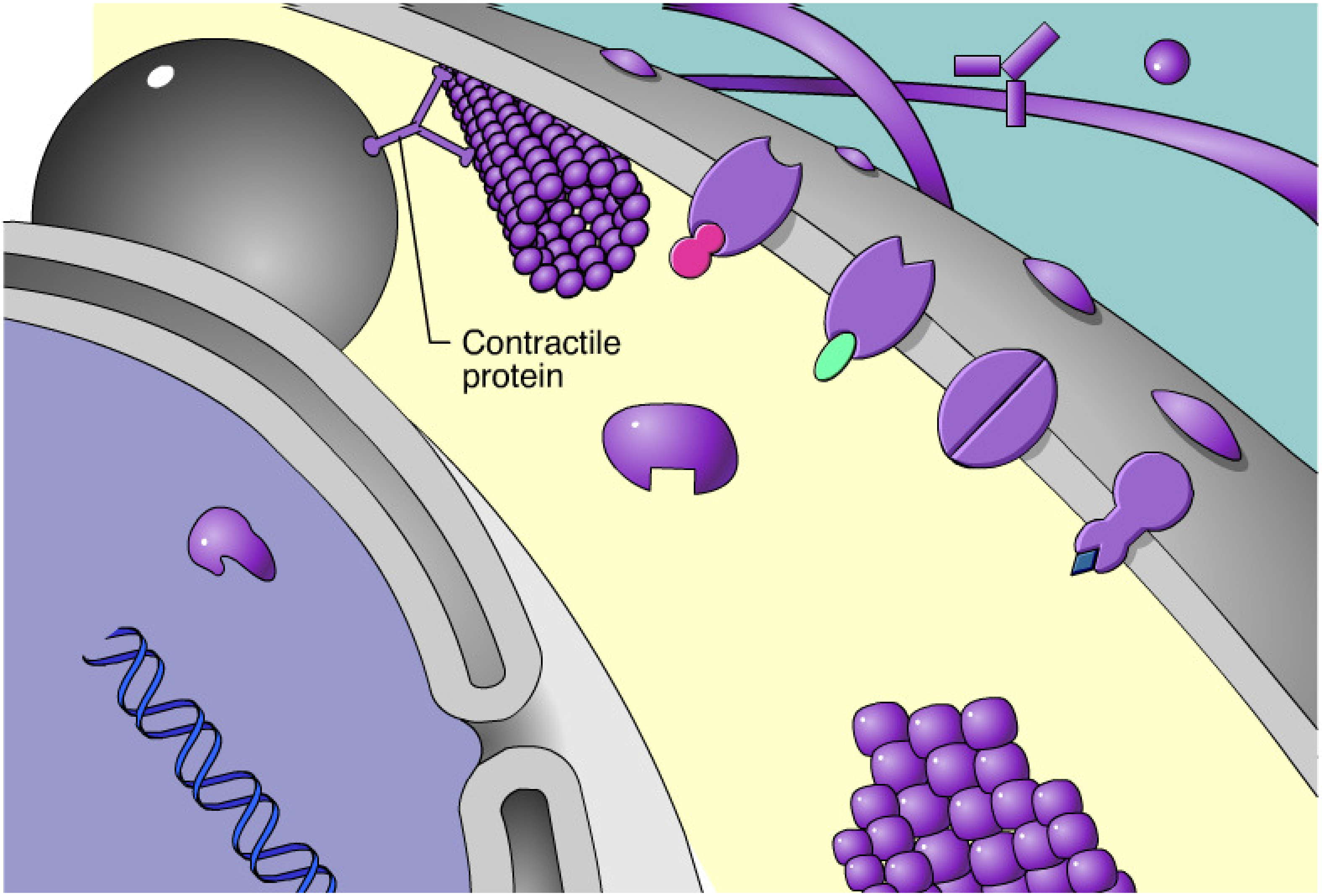
Video: Cholesterol Space Model



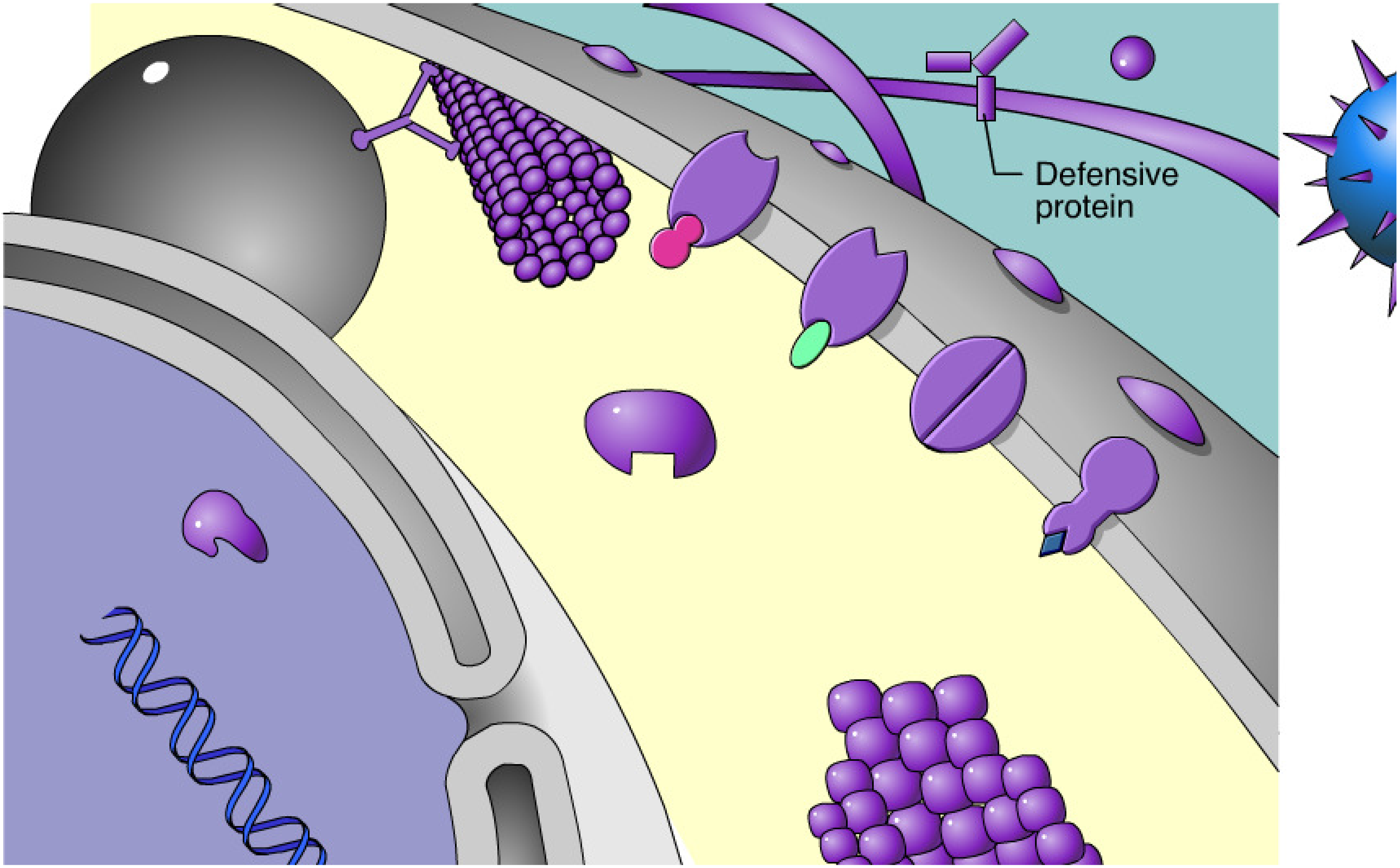
Video: Cholesterol Stick Model

Concept 3.5: Proteins include a diversity of structures, resulting in a wide range of functions

- Proteins account for more than 50% of the dry mass of most cells
- Protein functions include defense, storage, transport, cellular communication, movement, and structural support

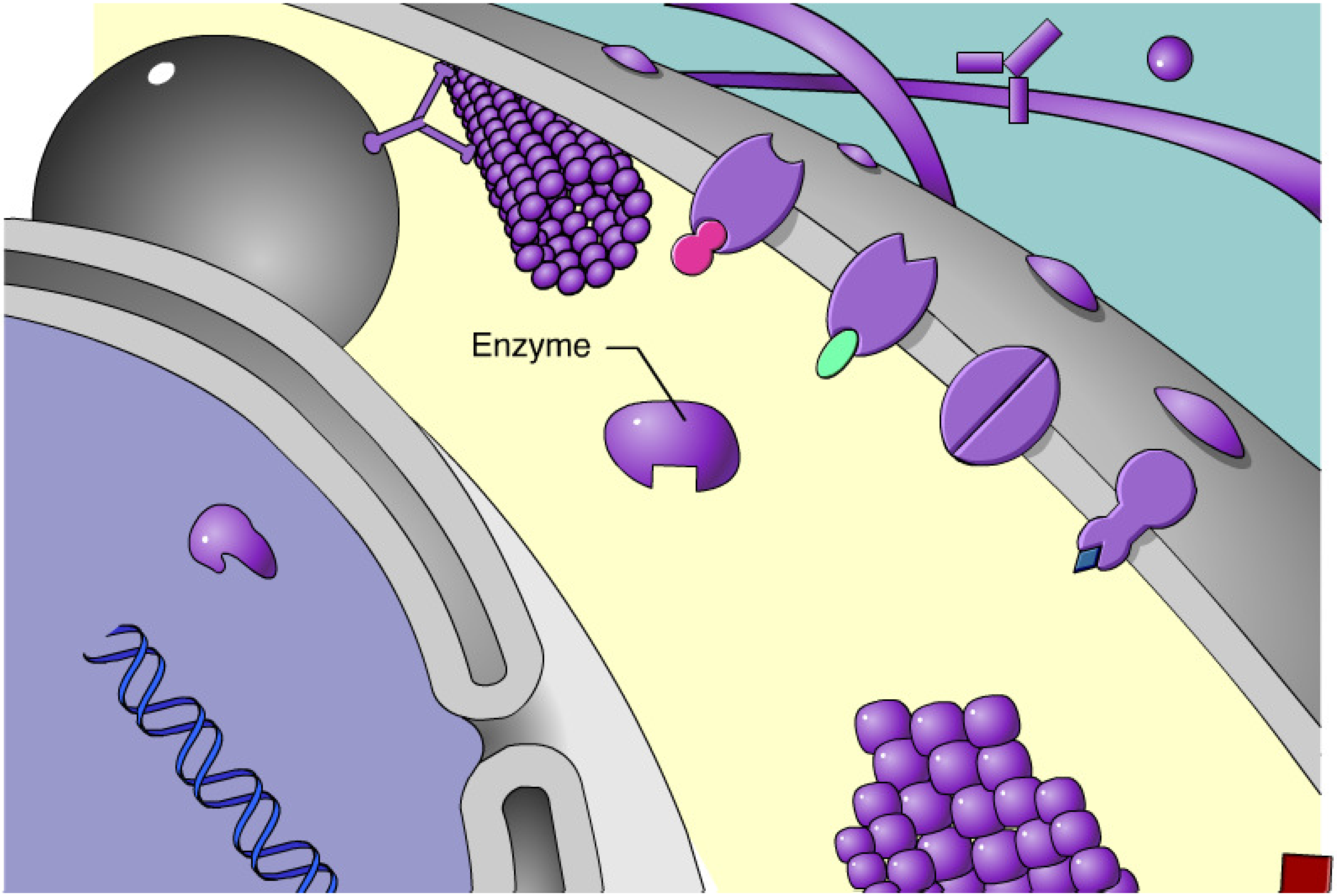


Animation: Contractile Proteins
Right click slide / Select play



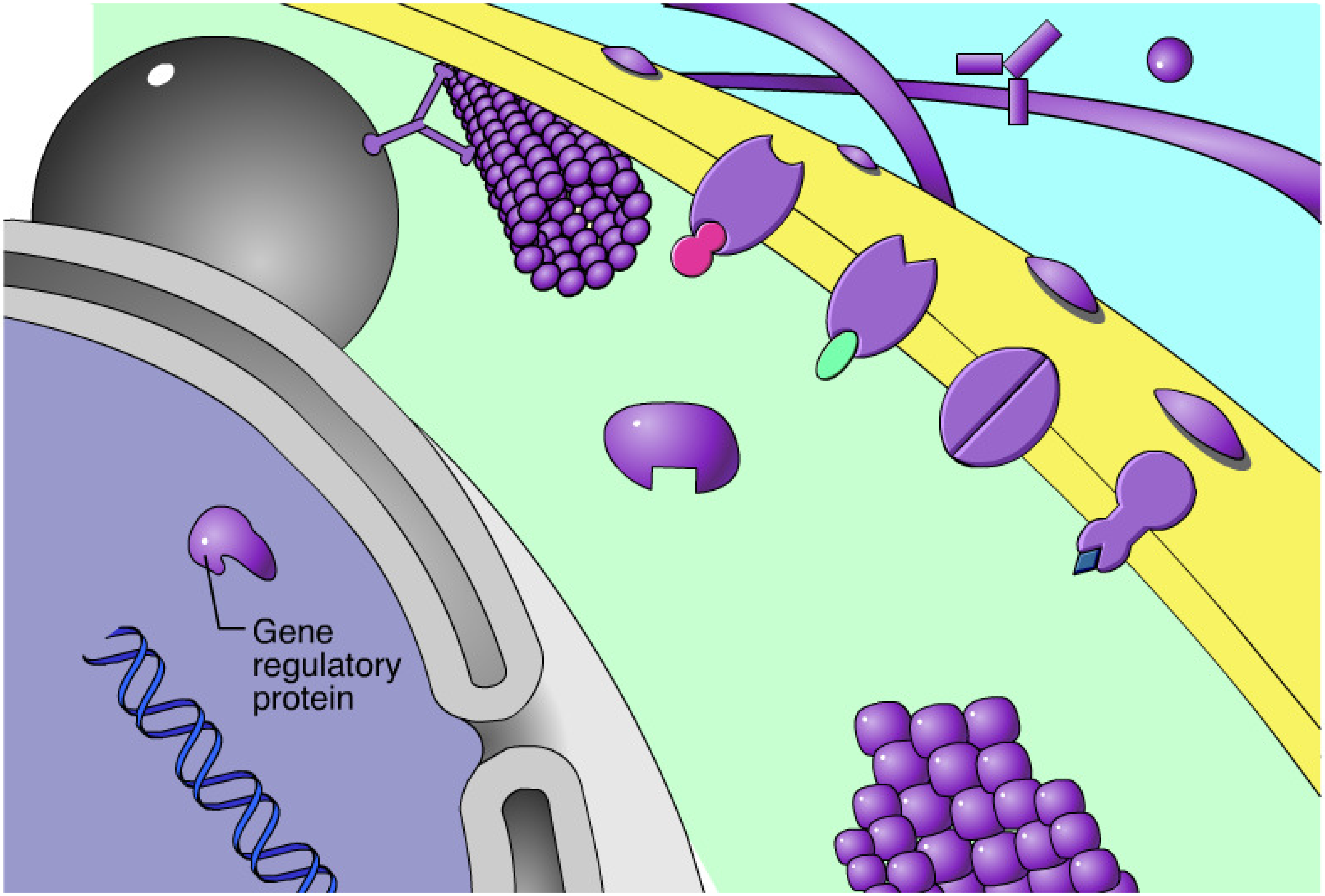
Animation: Defensive Proteins

Right click slide / Select play



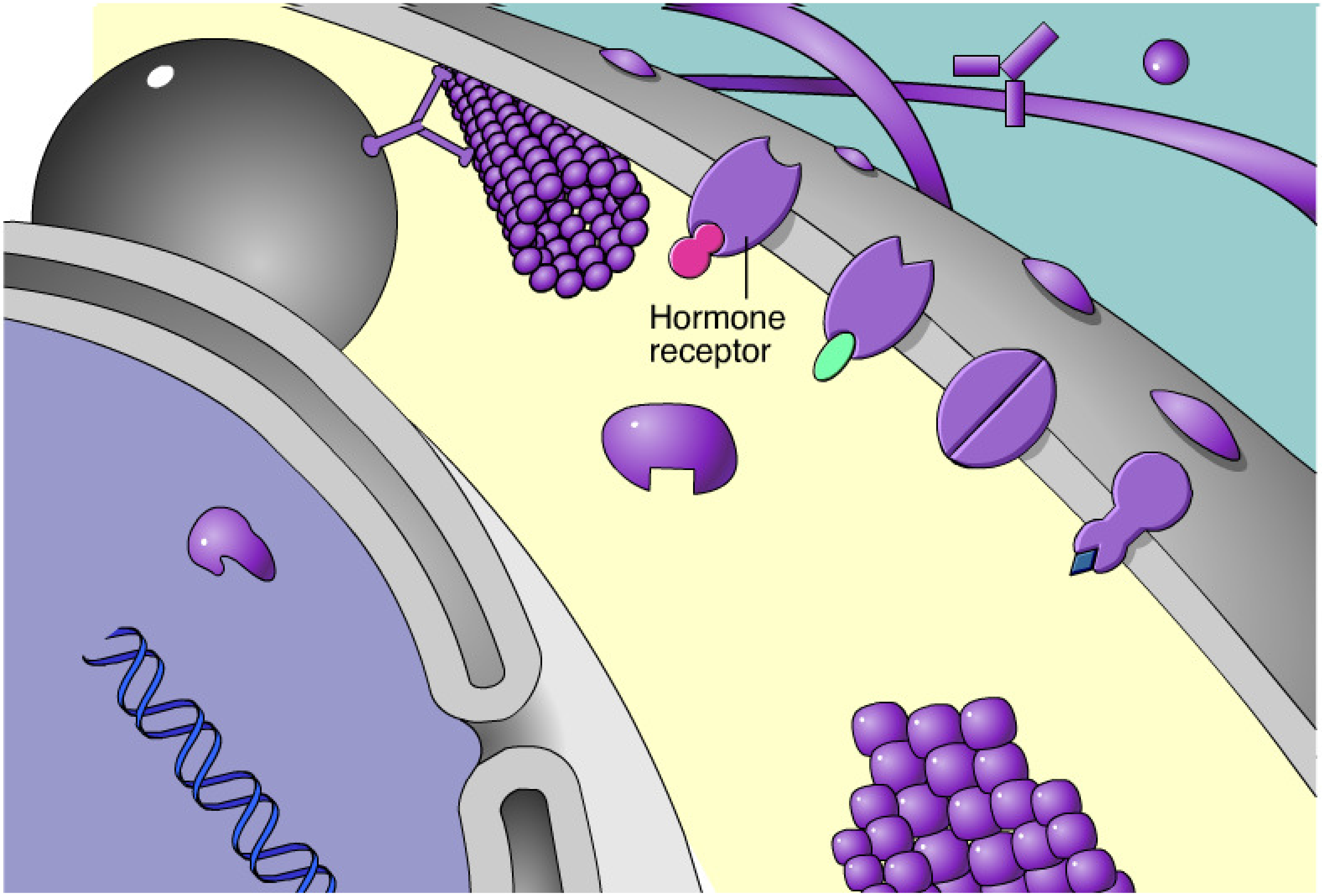
Animation: Enzymes

Right click slide / Select play

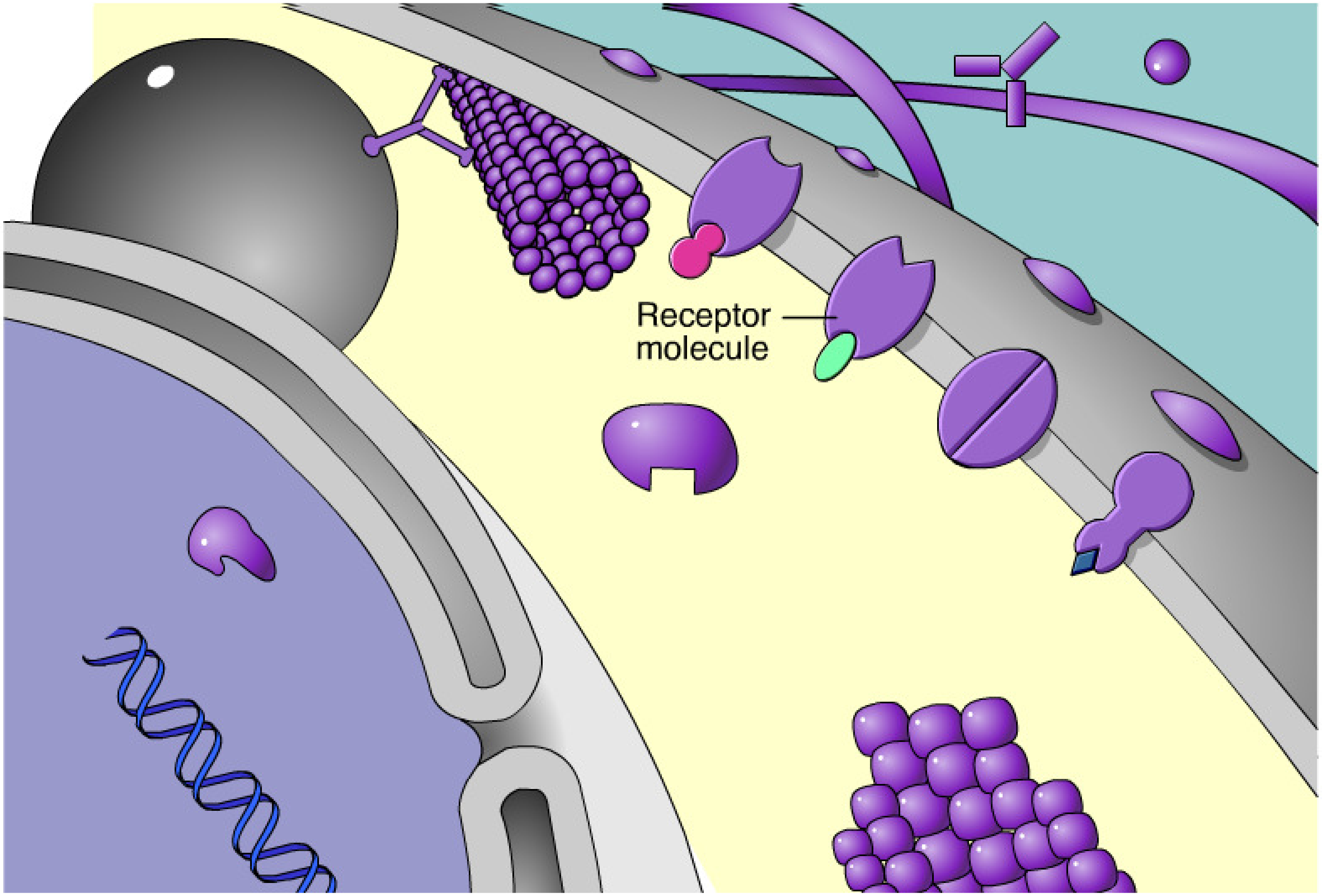


Animation: Gene Regulatory Proteins

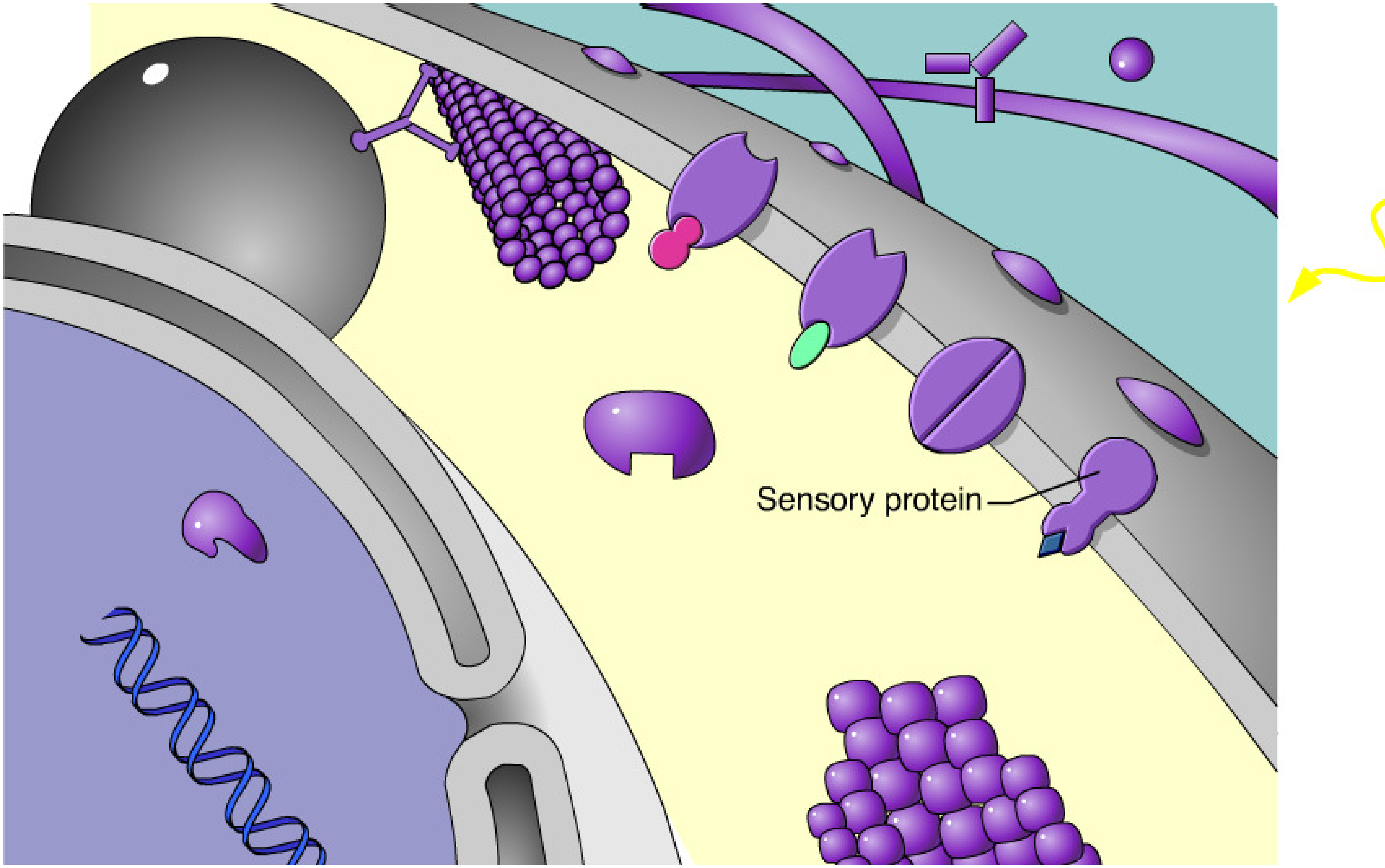
Right click slide / Select play



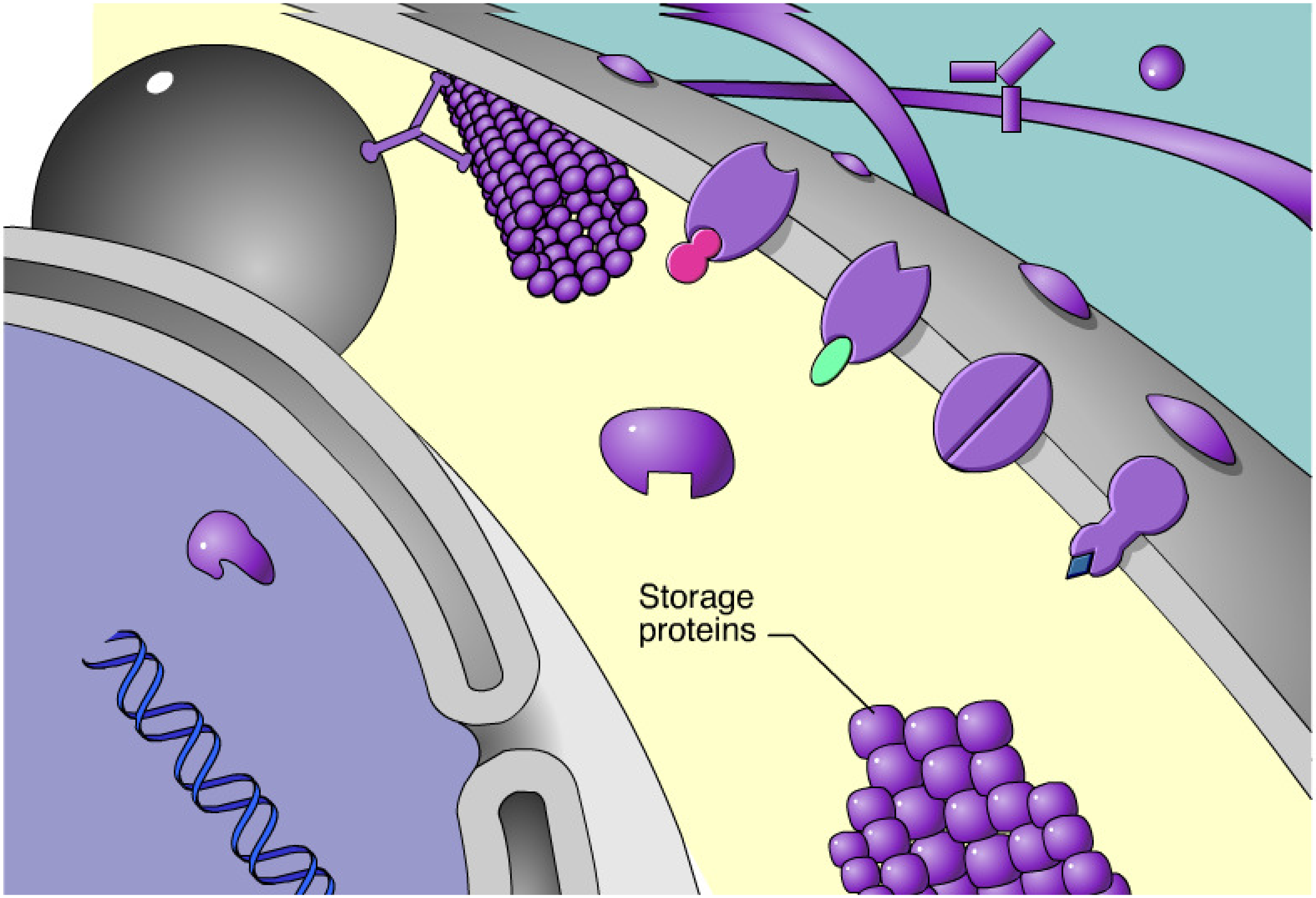
Animation: Hormonal Proteins
Right click slide / Select play



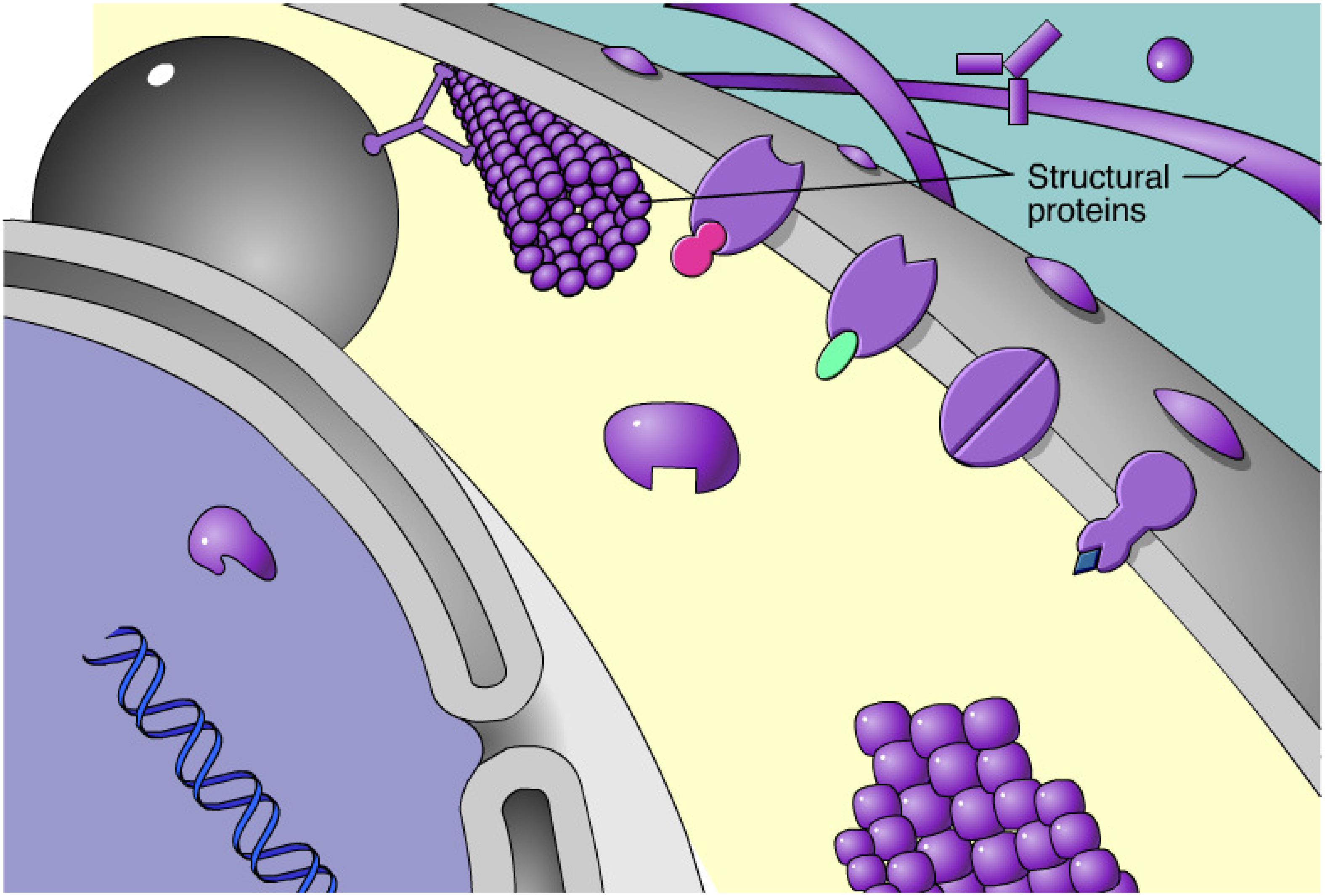
Animation: Receptor Proteins
Right click slide / Select Play



Animation: Sensory Proteins
Right click slide / Select play

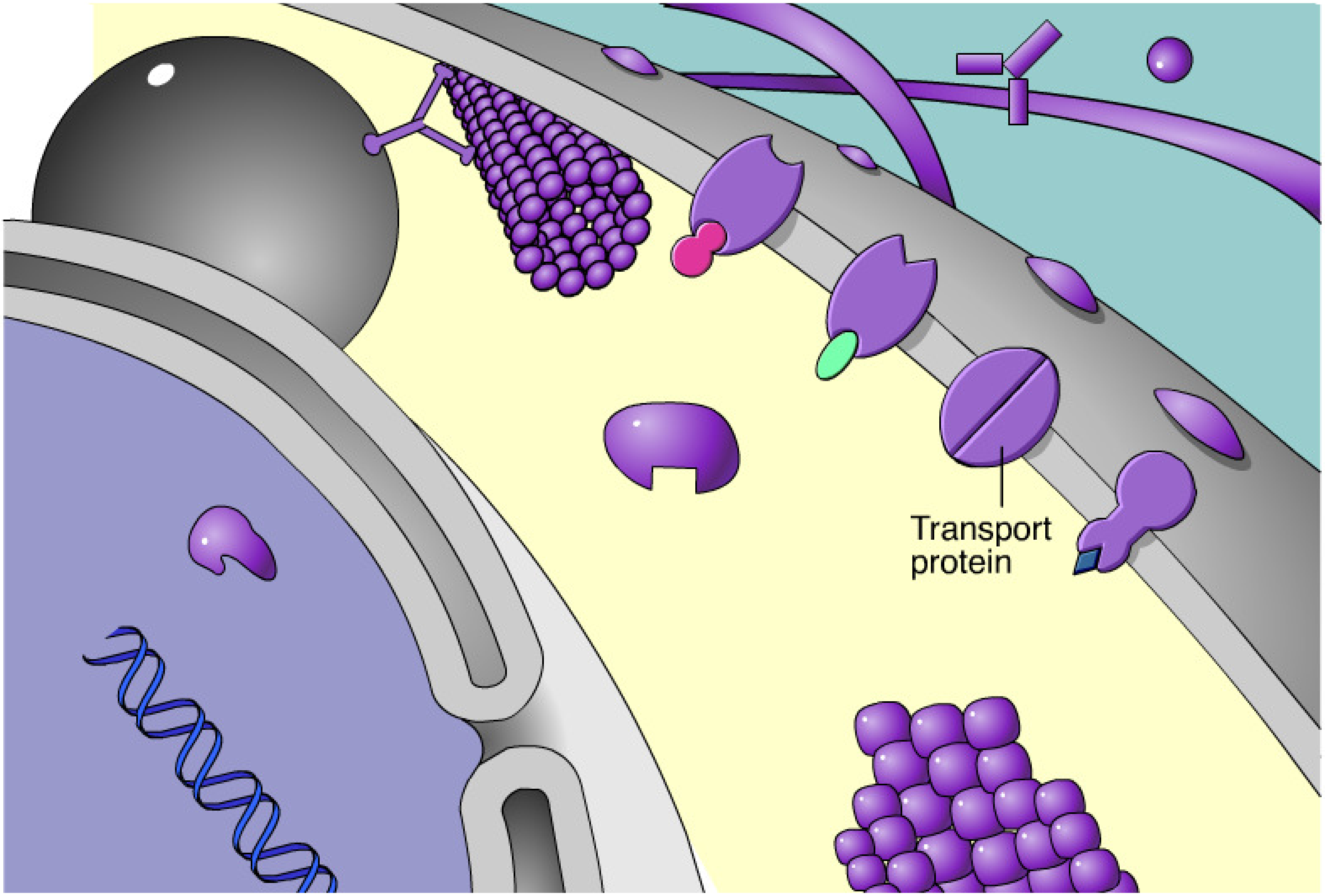


Animation: Storage Proteins
Right click slide / Select play



Animation: Structural Proteins

Right click slide / Select play



Animation: Transport Proteins

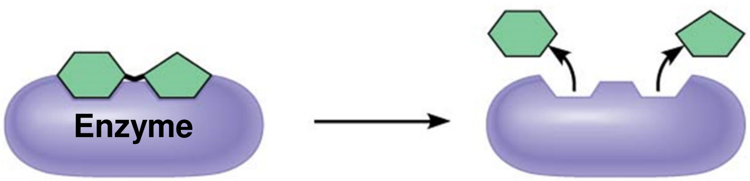
Right click slide / Select play

Figure 3.16a

Enzymatic proteins

Function: Selective acceleration of chemical reactions

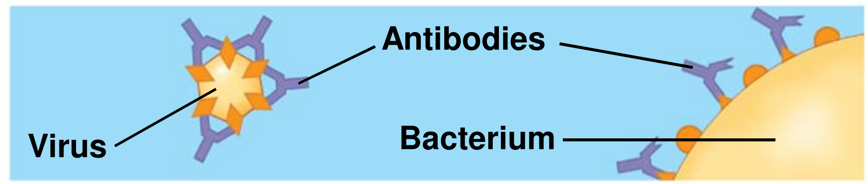
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins

Function: Protection against disease

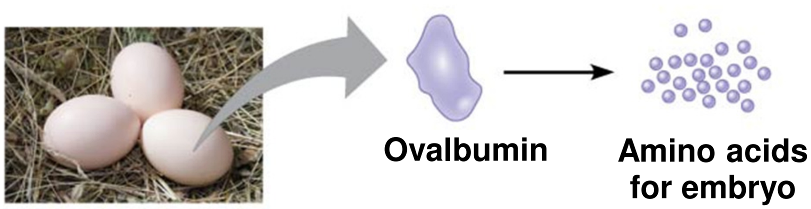
Example: Antibodies inactivate and help destroy viruses and bacteria.



Storage proteins

Function: Storage of amino acids

Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.

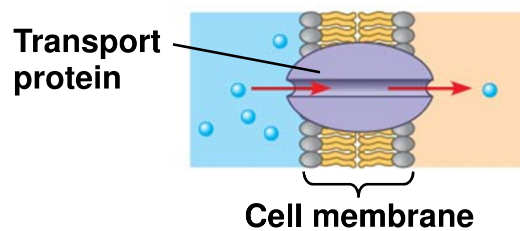


Figure 3.16aa

Enzymatic proteins

Function: Selective acceleration of chemical reactions

Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.

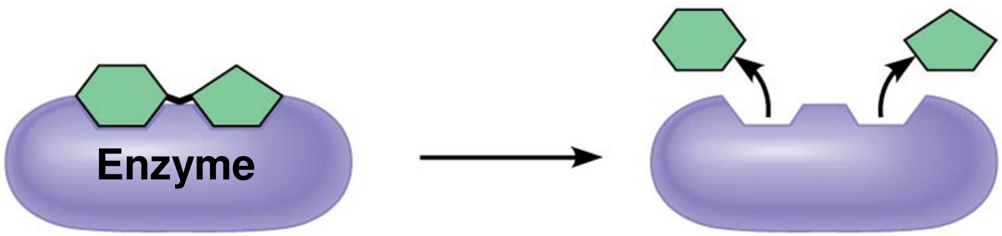


Figure 3.16ab

Defensive proteins

Function: Protection against disease

Example: Antibodies inactivate and help destroy viruses and bacteria.

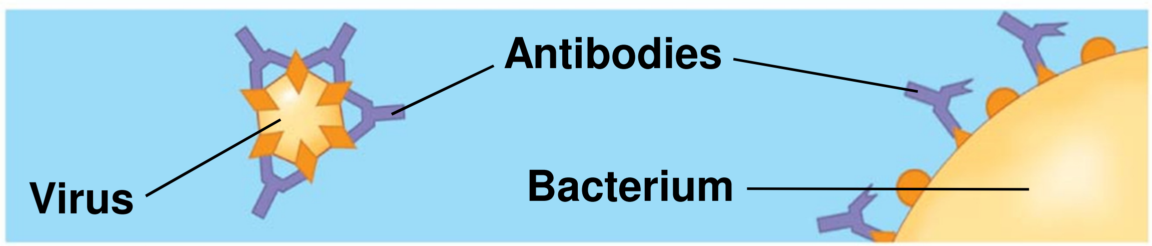


Figure 3.16ac

Storage proteins

Function: Storage of amino acids

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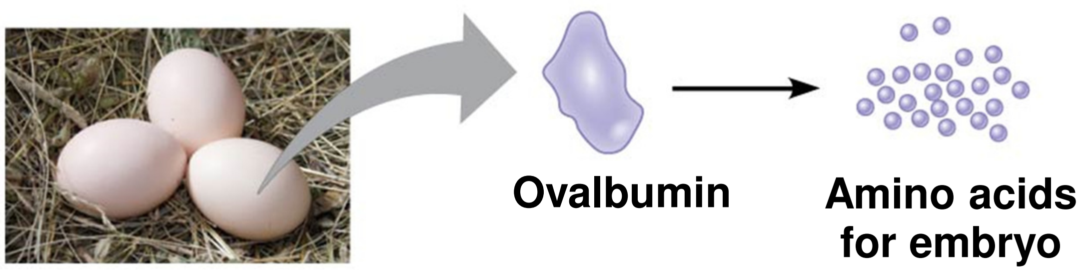


Figure 3.16ad

Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.

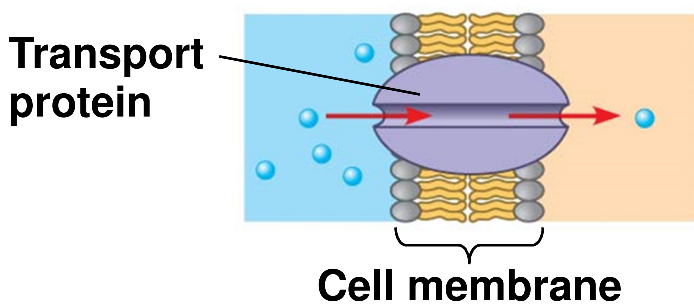
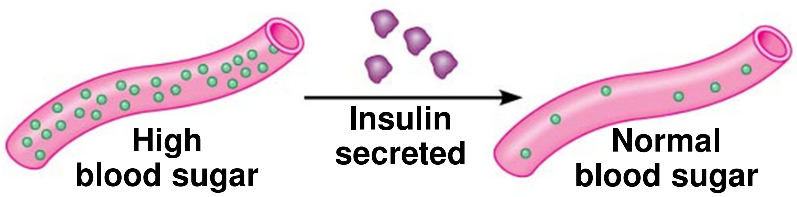


Figure 3.16b

Hormonal proteins

Function: Coordination of an organism's activities

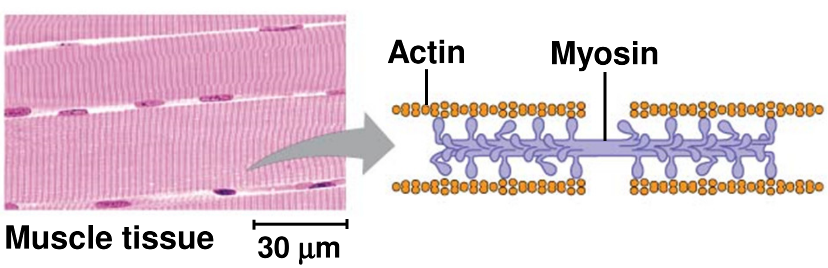
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



Contractile and motor proteins

Function: Movement

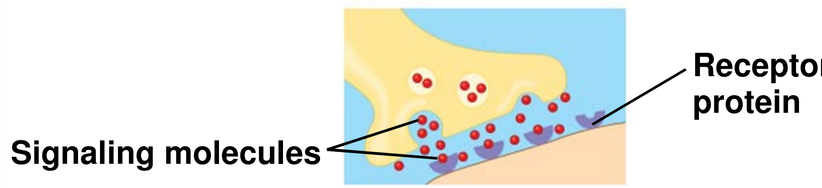
Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.

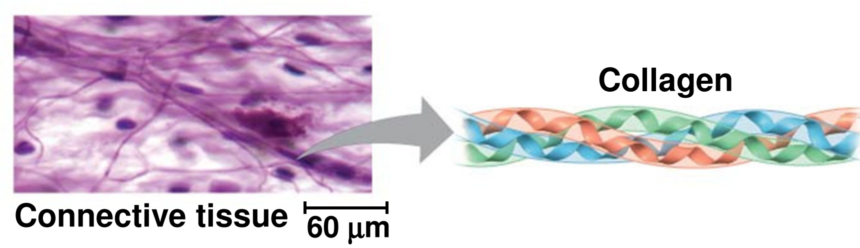


Figure 3.16ba

Hormonal proteins

Function: Coordination of an organism's activities

Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.

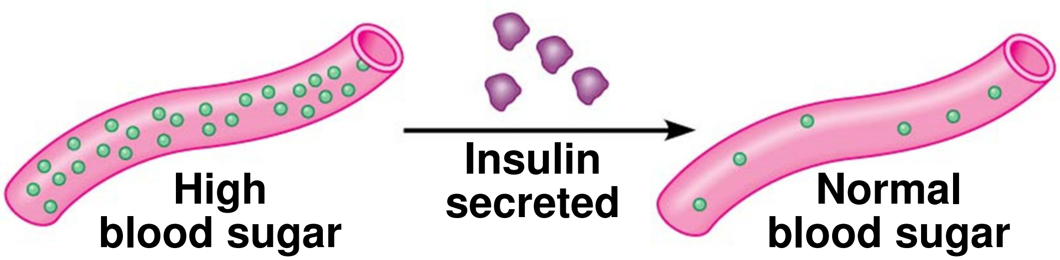


Figure 3.16bb

Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.

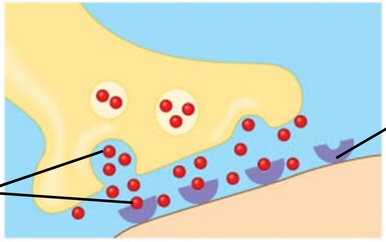


Figure 3.16bc

Contractile and motor proteins

Function: Movement

Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.

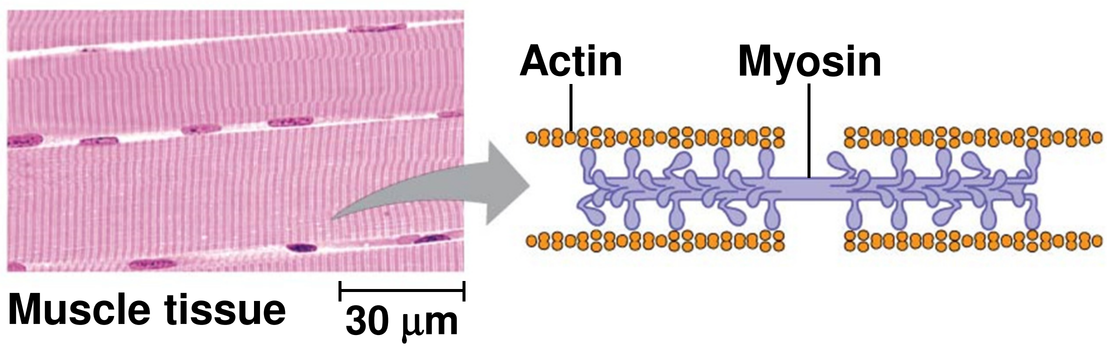
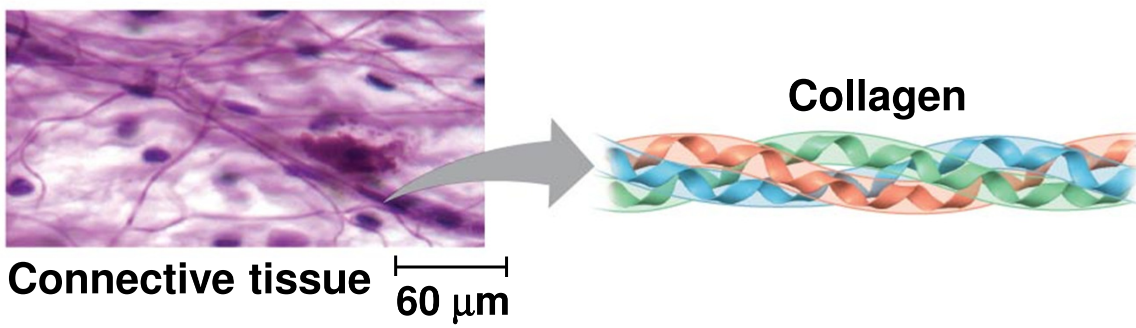


Figure 3.16bd

Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



- Life would not be possible without enzymes
- Enzymatic proteins act as **catalysts**, to speed up chemical reactions without being consumed by the reaction

- **Polypeptides** are unbranched polymers built from the same set of 20 amino acids
- A **protein** is a biologically functional molecule that consists of one or more polypeptides

Amino Acids

- **Amino acids** are organic molecules with carboxyl and amino groups
- Amino acids differ in their properties due to differing side chains, called R groups

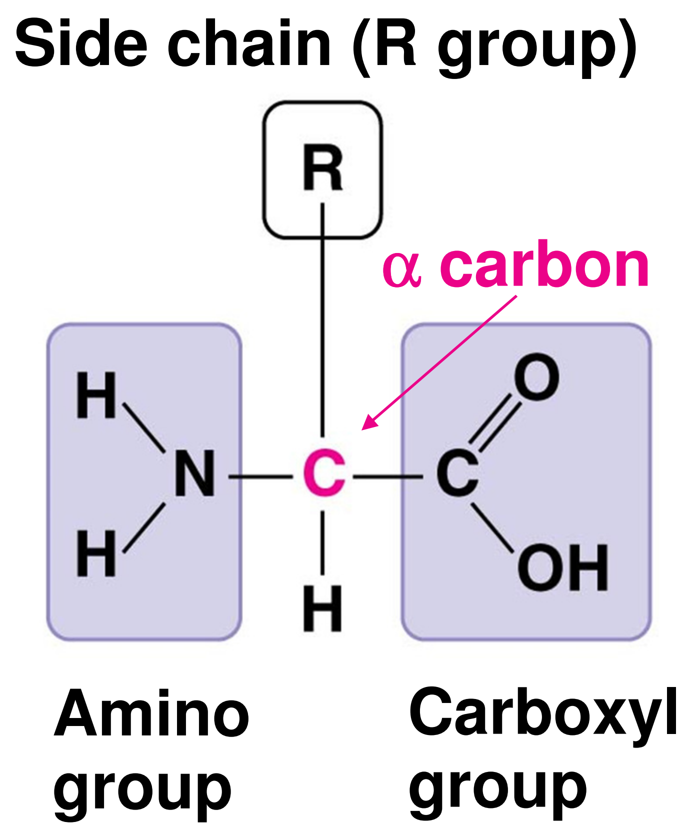


Figure 3.17a

Nonpolar side chains; hydrophobic

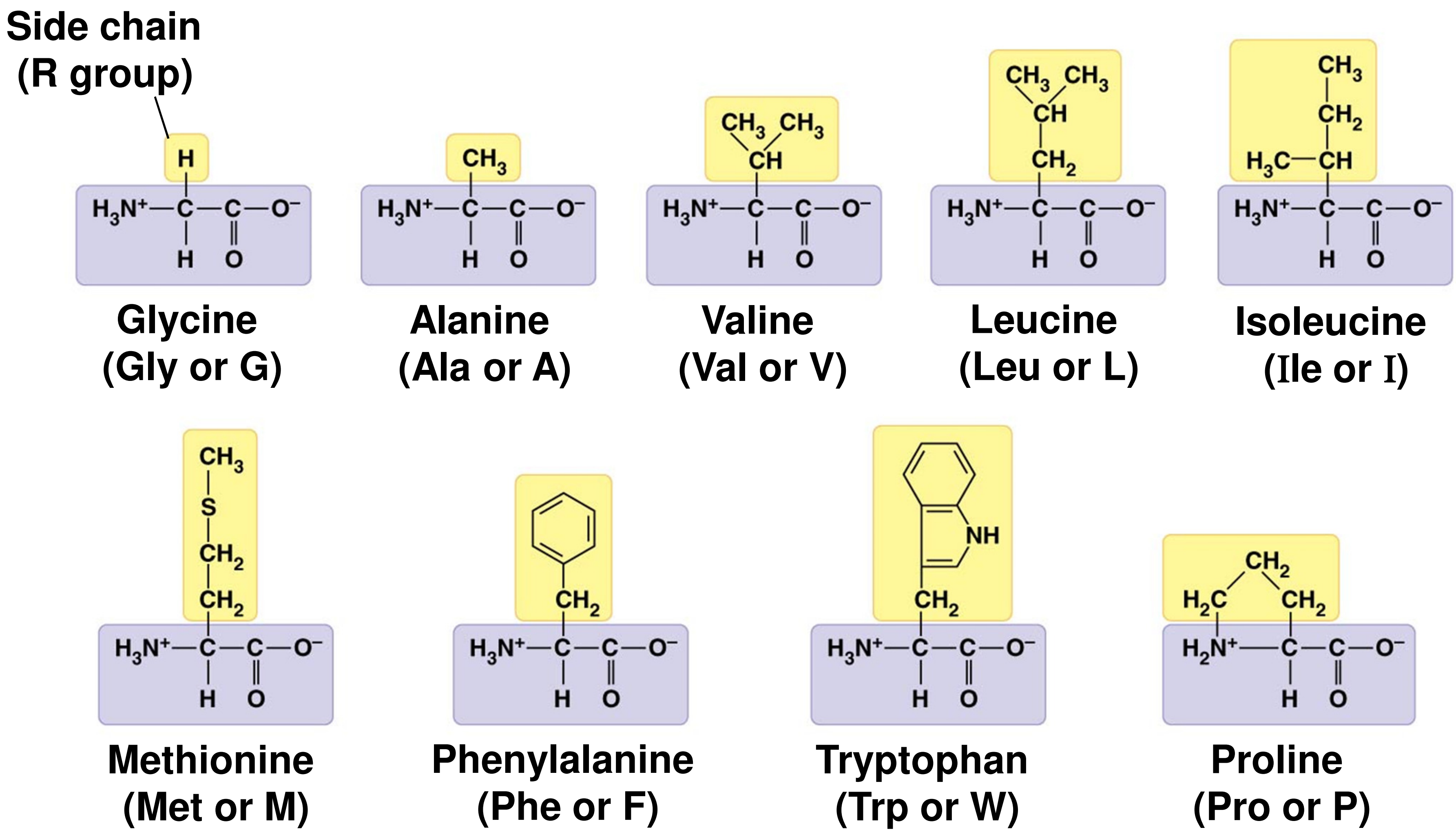


Figure 3.17b

Polar side chains; hydrophilic

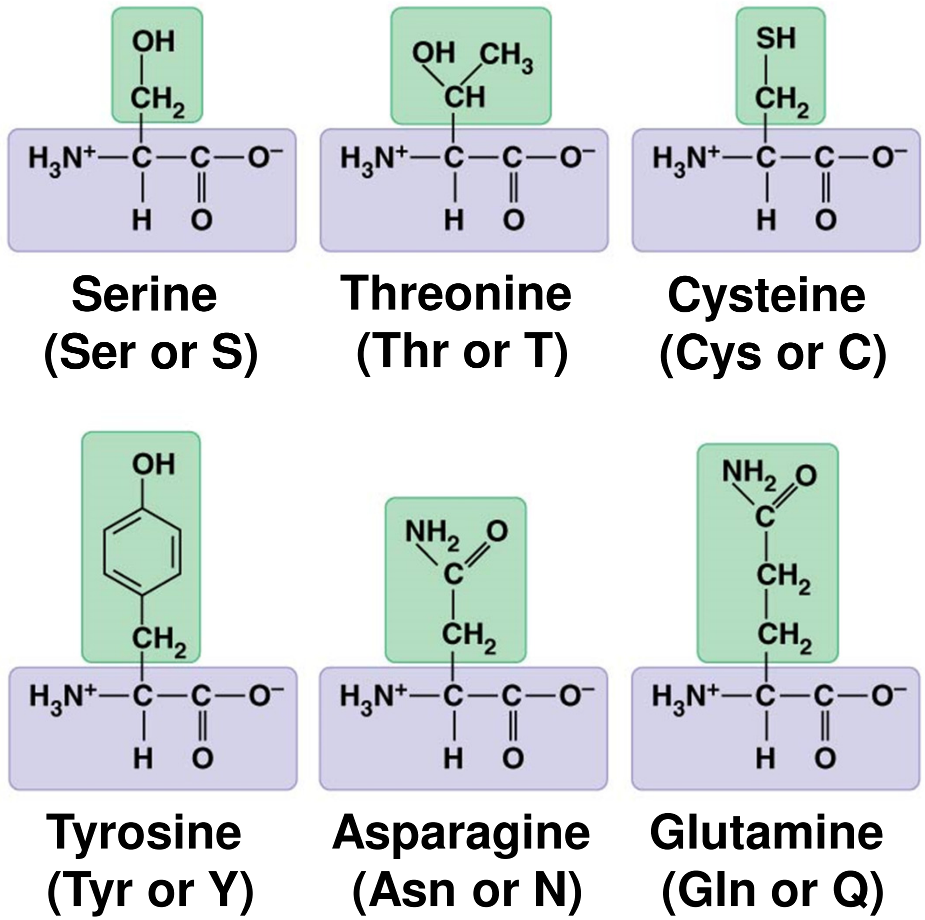
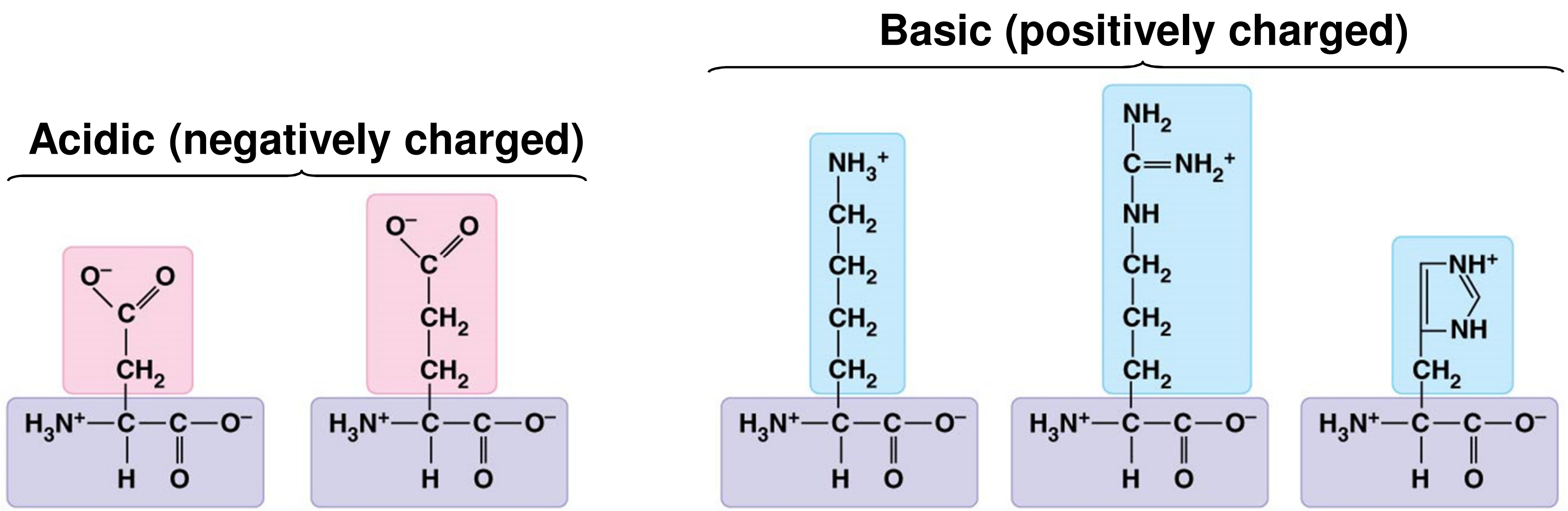


Figure 3.17c

Electrically charged side chains; hydrophilic

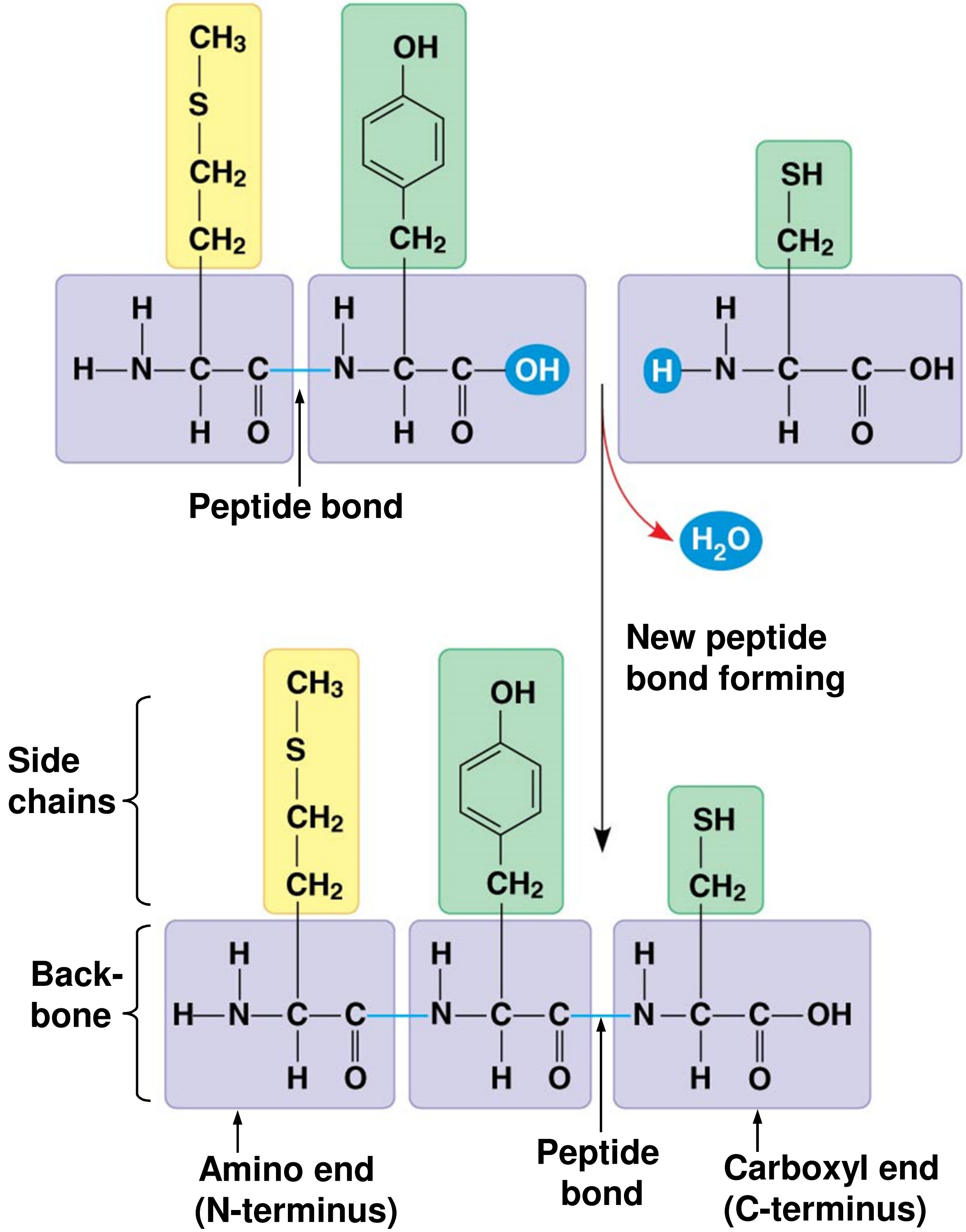


Aspartic acid (Asp or D) | Glutamic acid (Glu or E) | Lysine (Lys or K) | Arginine (Arg or R) | Histidine (His or H)

Polypeptides

- Amino acids are linked by **peptide bonds**
- A polypeptide is a polymer of amino acids
- Polypeptides range in length from a few to more than a thousand monomers
- Each polypeptide has a unique linear sequence of amino acids, with a carboxyl end (C-terminus) and an amino end (N-terminus)

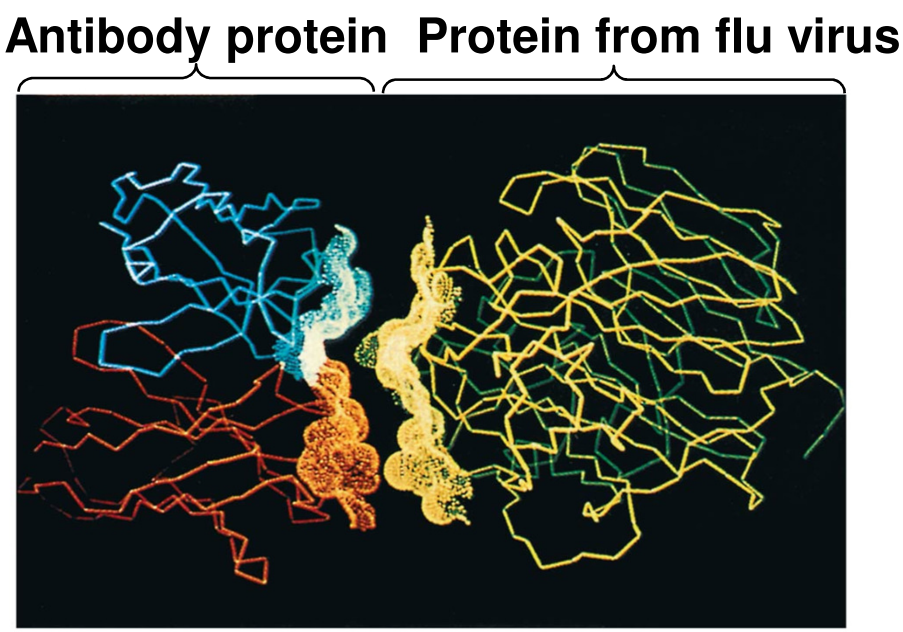
Figure 3.18



CH3
S
CH2
CH2
OH
CH2
SH
CH2
H
H—N—C—C
H O
N—C—C
OH
H—N—C—C—OH
Peptide bond
H2O
New peptide
bond forming
Side
chains
Back-
bone
Amino end
(N-terminus)
Peptide
bond
Carboxyl end
(C-terminus)

Protein Structure and Function

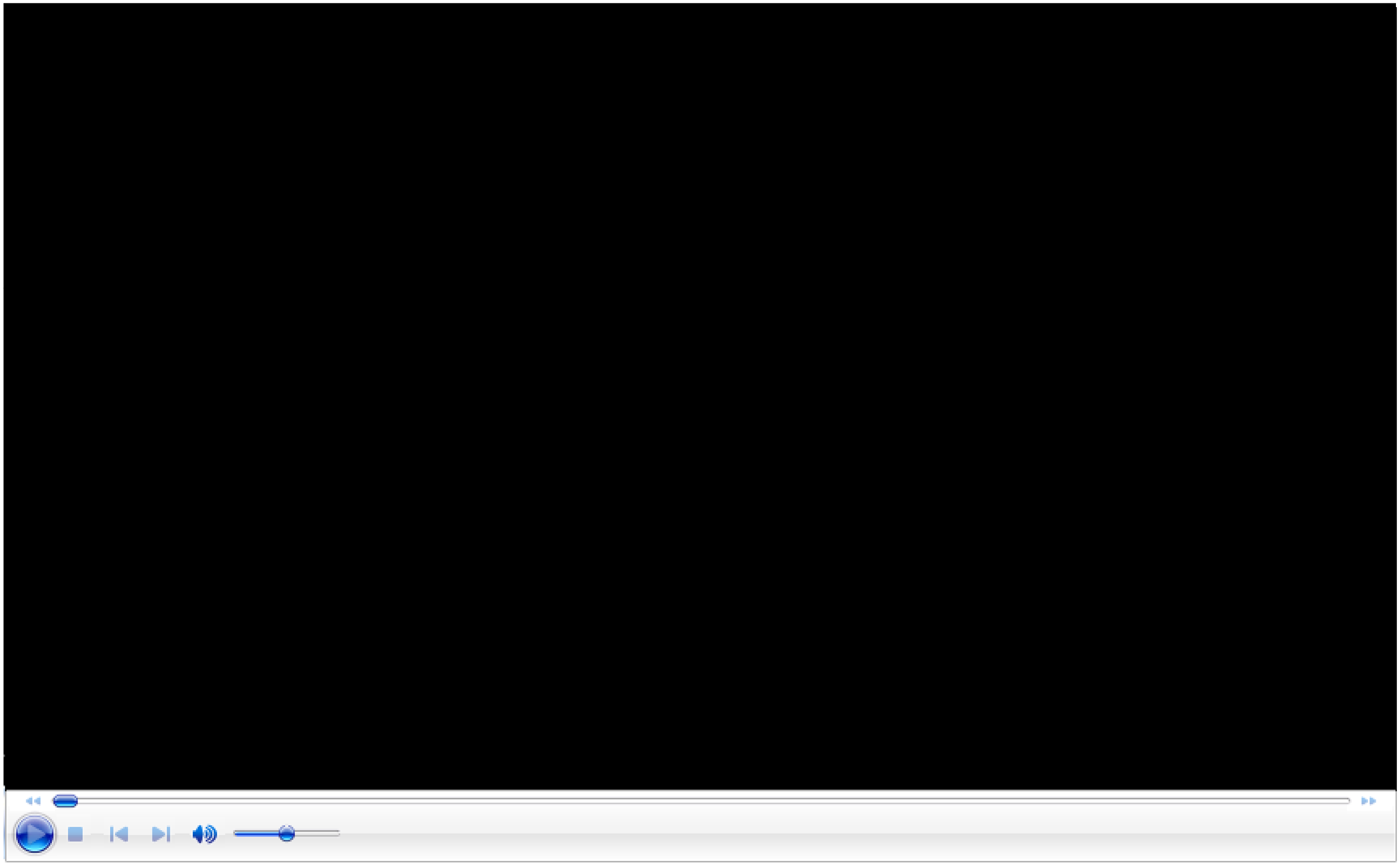
- A functional *protein* consists of one or more *polypeptides* precisely twisted, folded, and coiled into a unique shape
- The sequence of amino acids, determined genetically, leads to a protein's 3D structure
- A protein's structure determines its function
  - Shape affects function!



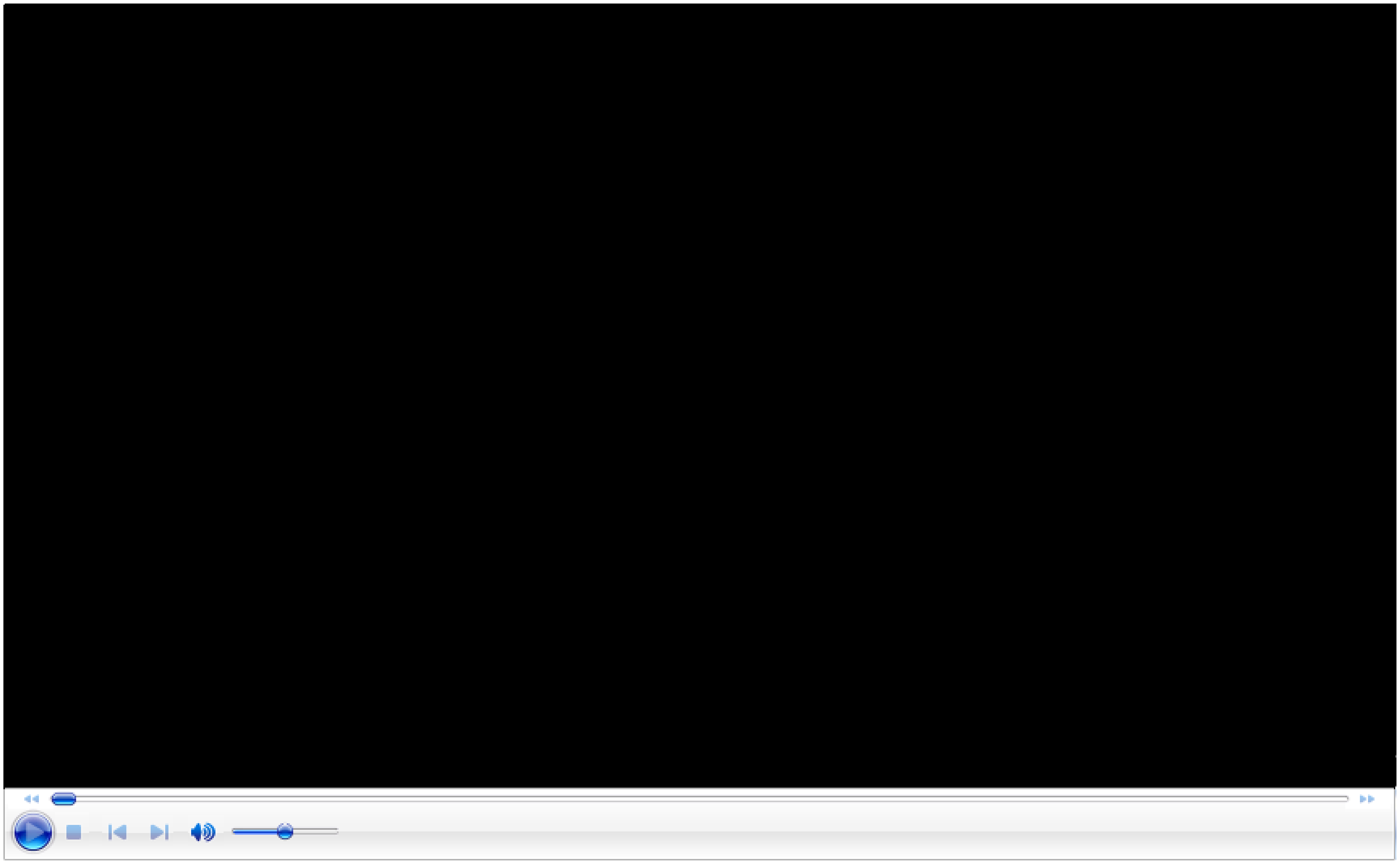
Four Levels of Protein Structure

- Proteins are very diverse, but share three superimposed levels of structure called primary, secondary, and tertiary structure
- A fourth level, quaternary structure, arises when a protein consists of more than one polypeptide chain

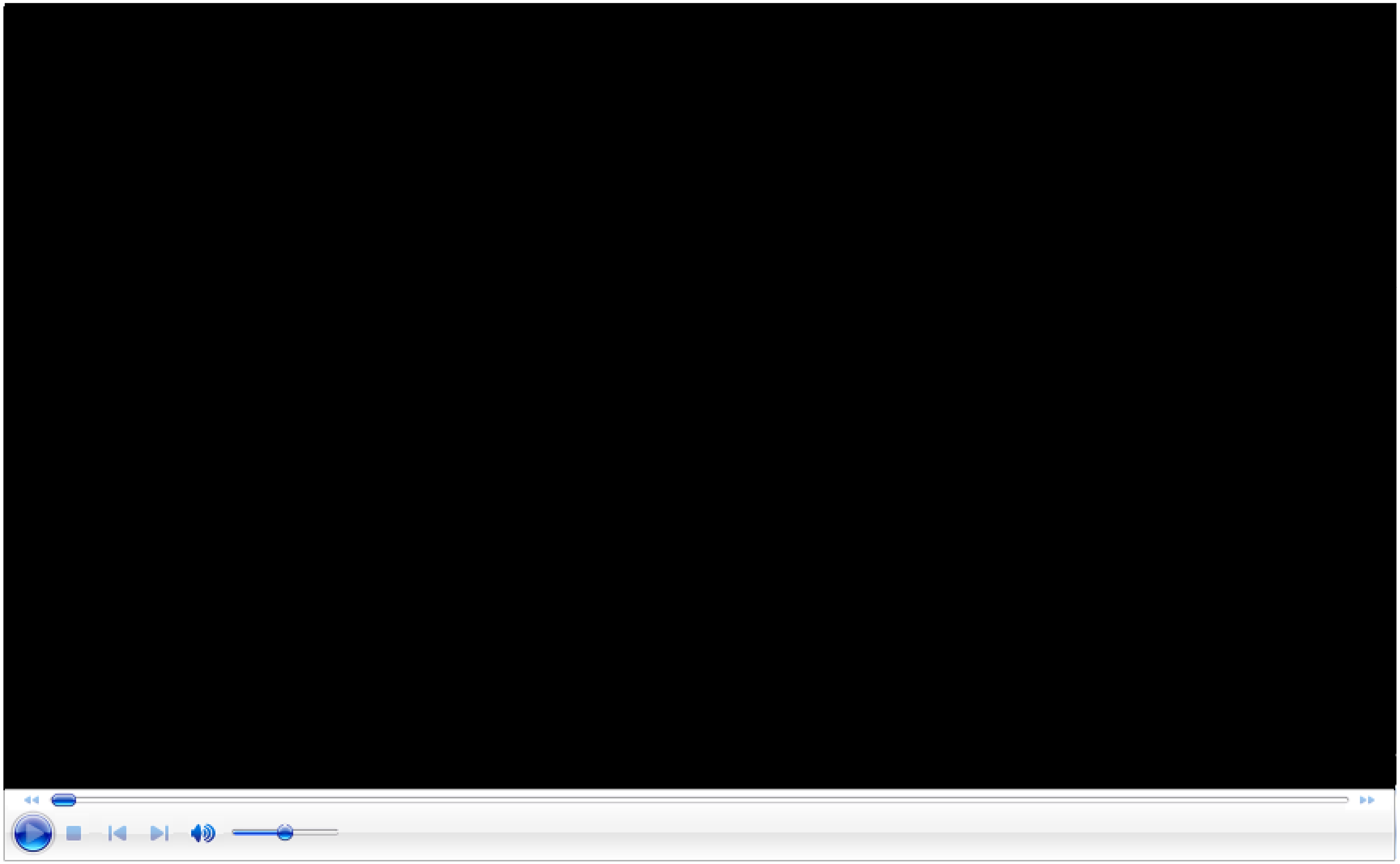
- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
  - Result of hydrogen bonds between repeating constituents of polypeptide backbone
  - Ex: α helix and β pleated sheet
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results from interactions between multiple polypeptide chains



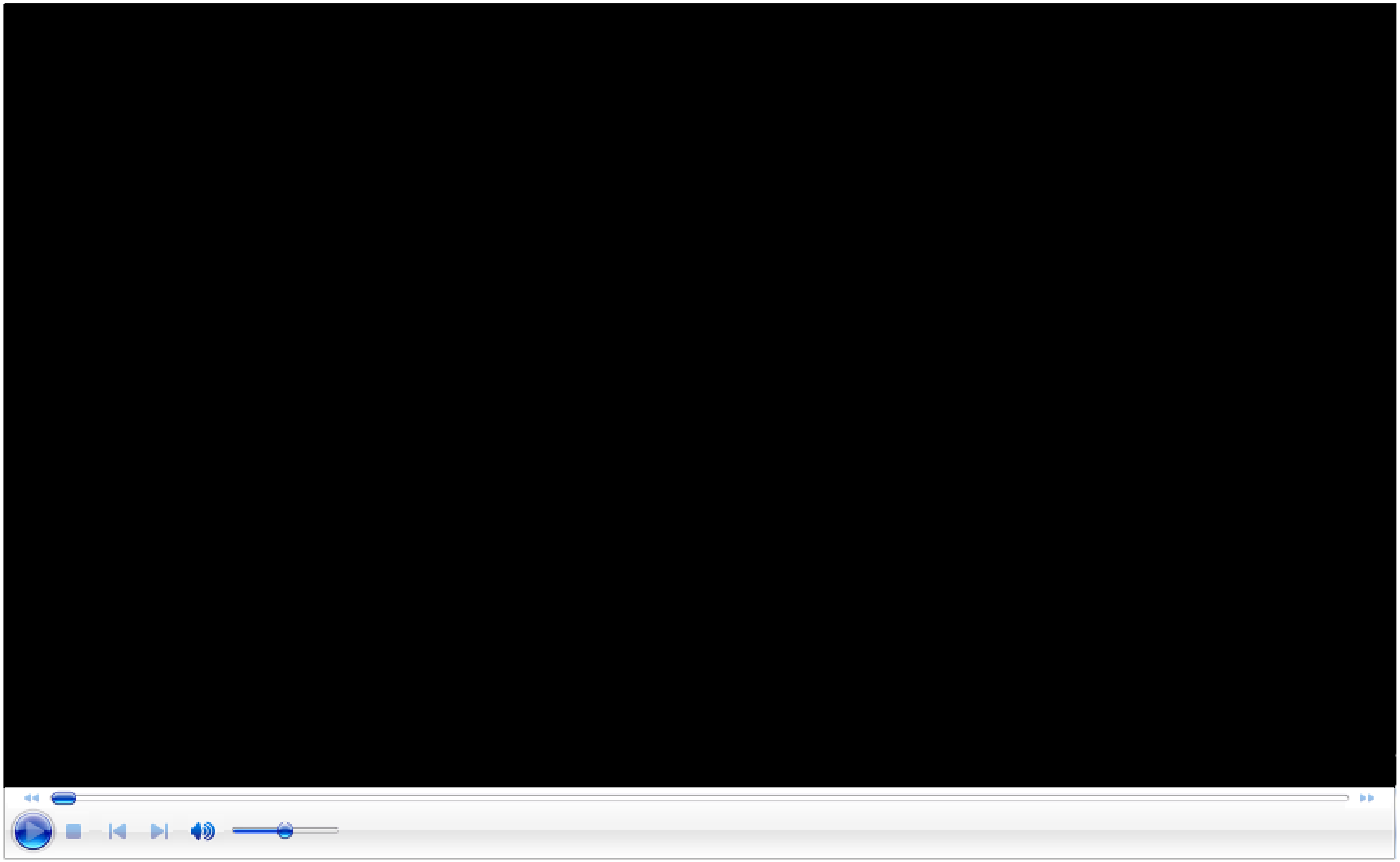
Video: Alpha Helix with No Side Chain



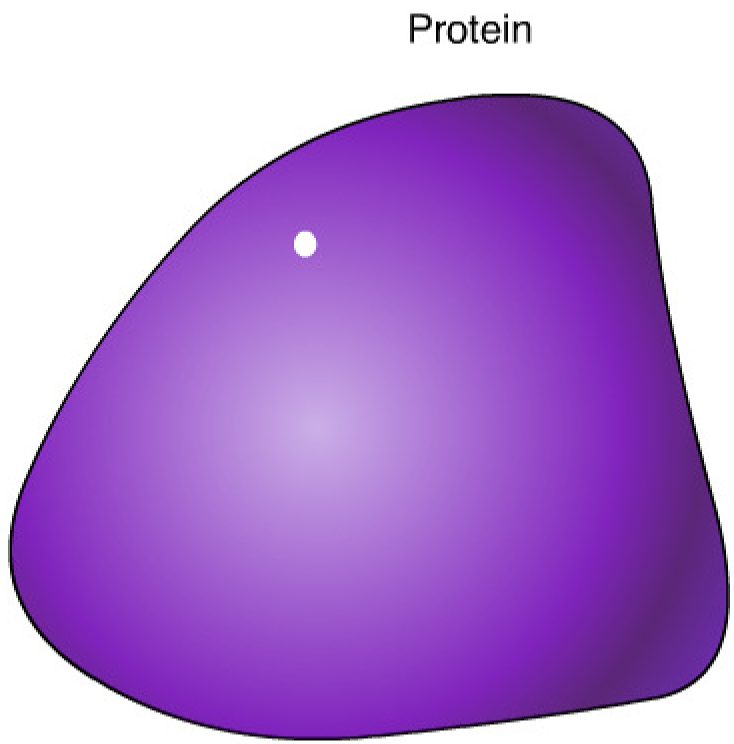
Video: Alpha Helix with Side Chain



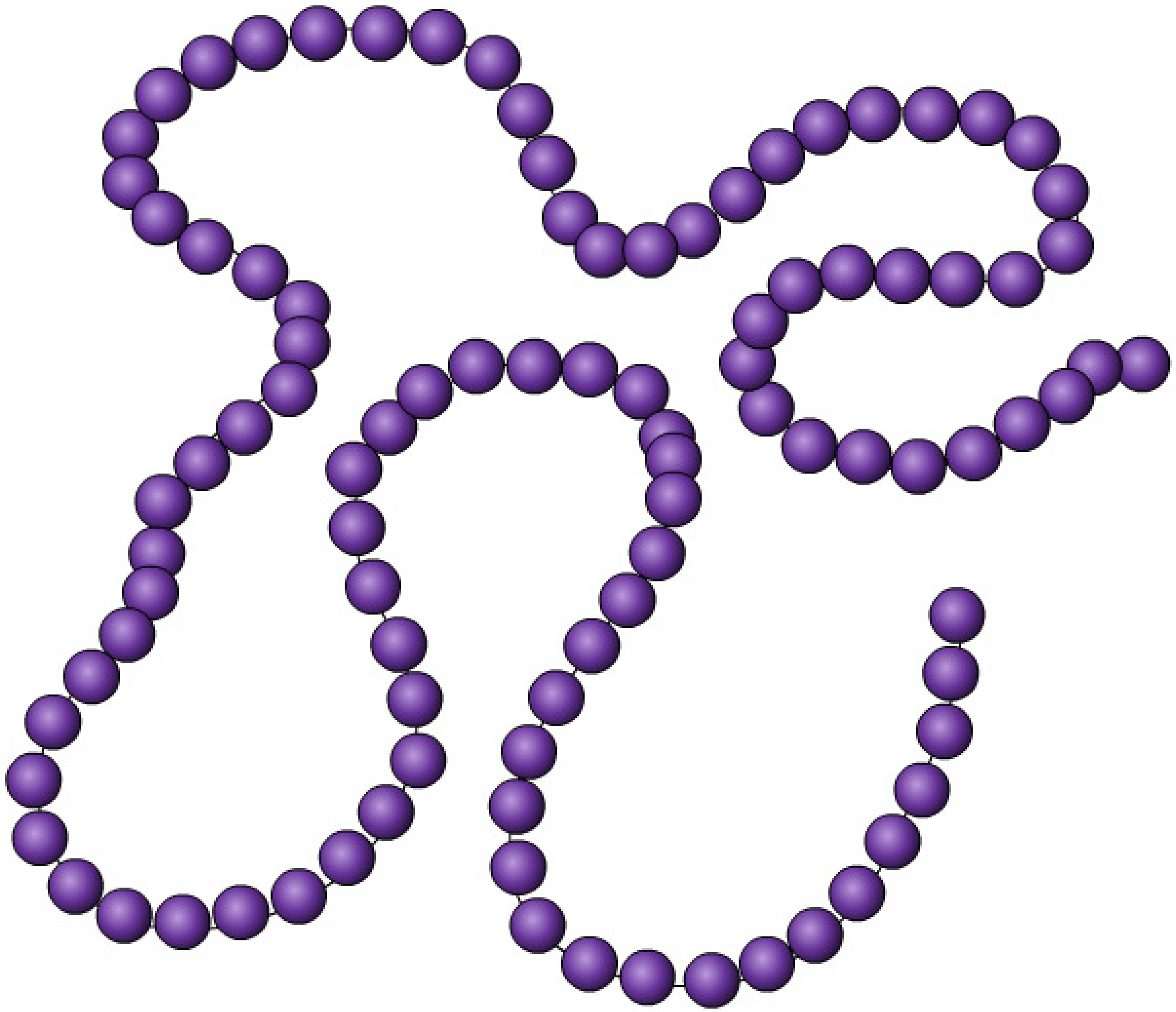
Video: Beta Pleated Sheet



Video: Beta Pleated Stick

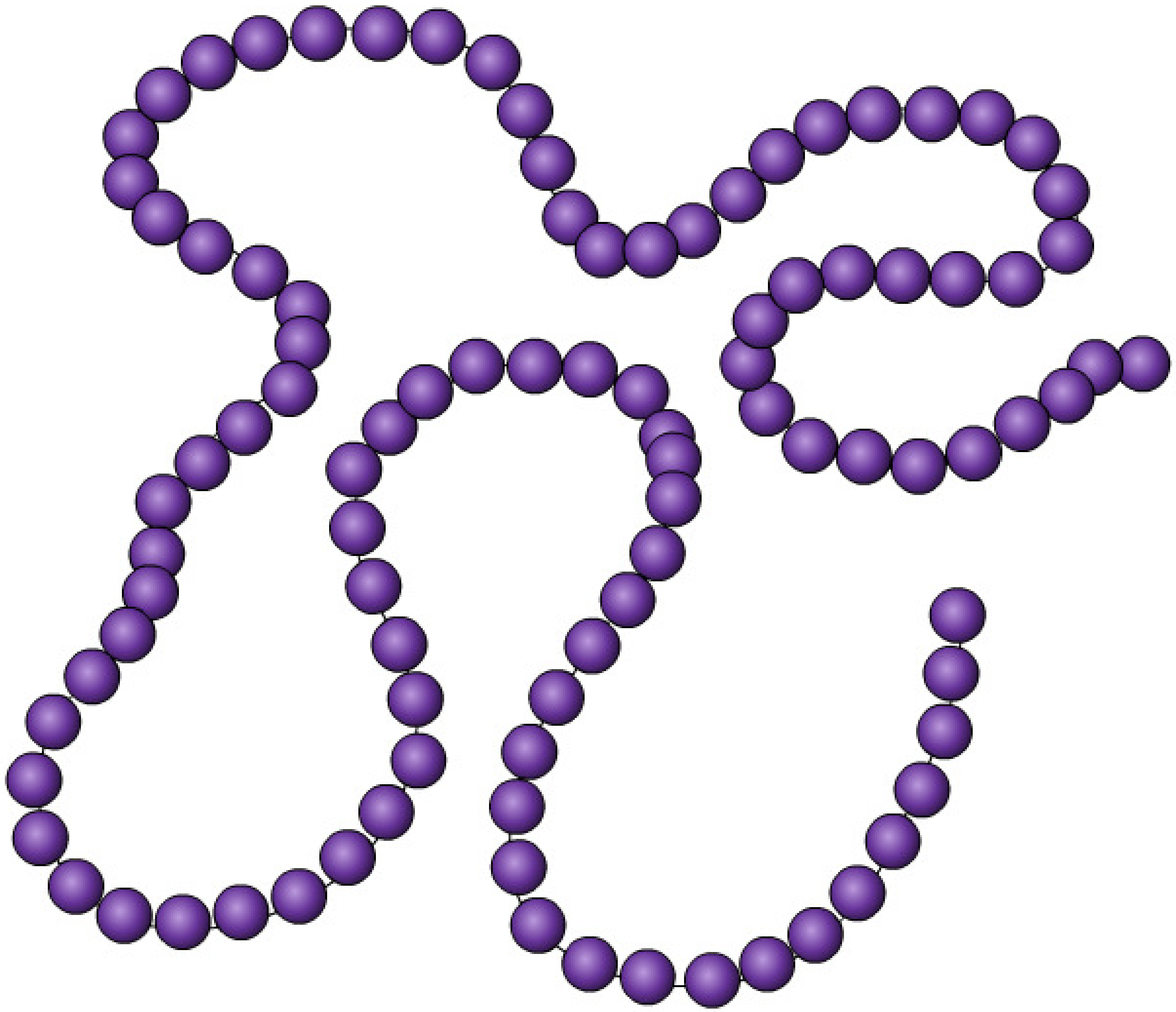


Animation: Introduction to Protein Structure
Right click slide / Select play



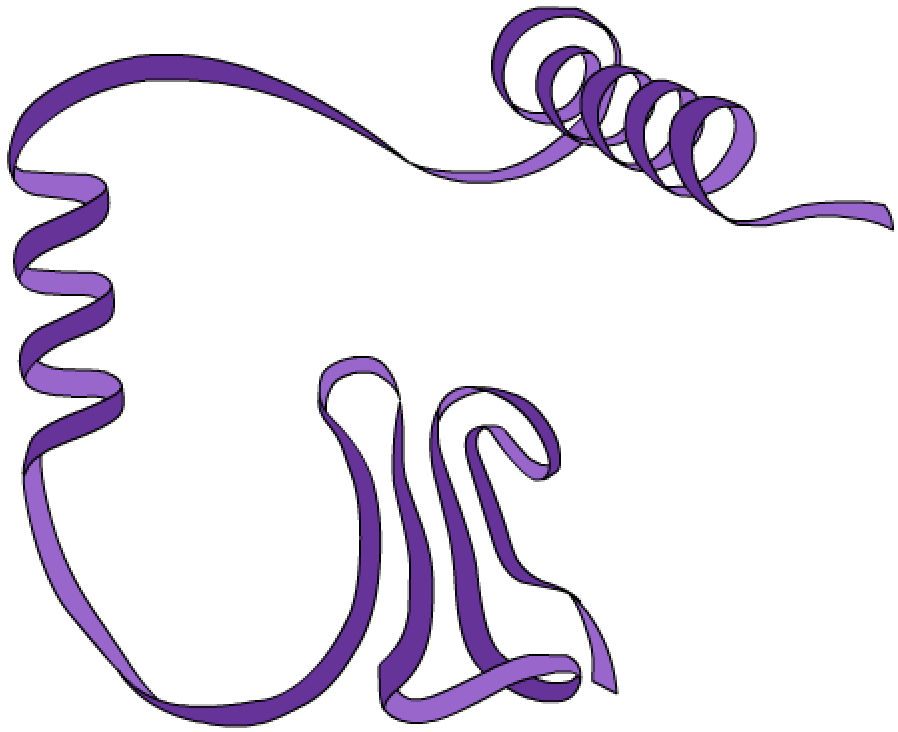
Animation: Primary Structure

Right click slide / Select play



Animation: Secondary Structure

Right click slide / Select play

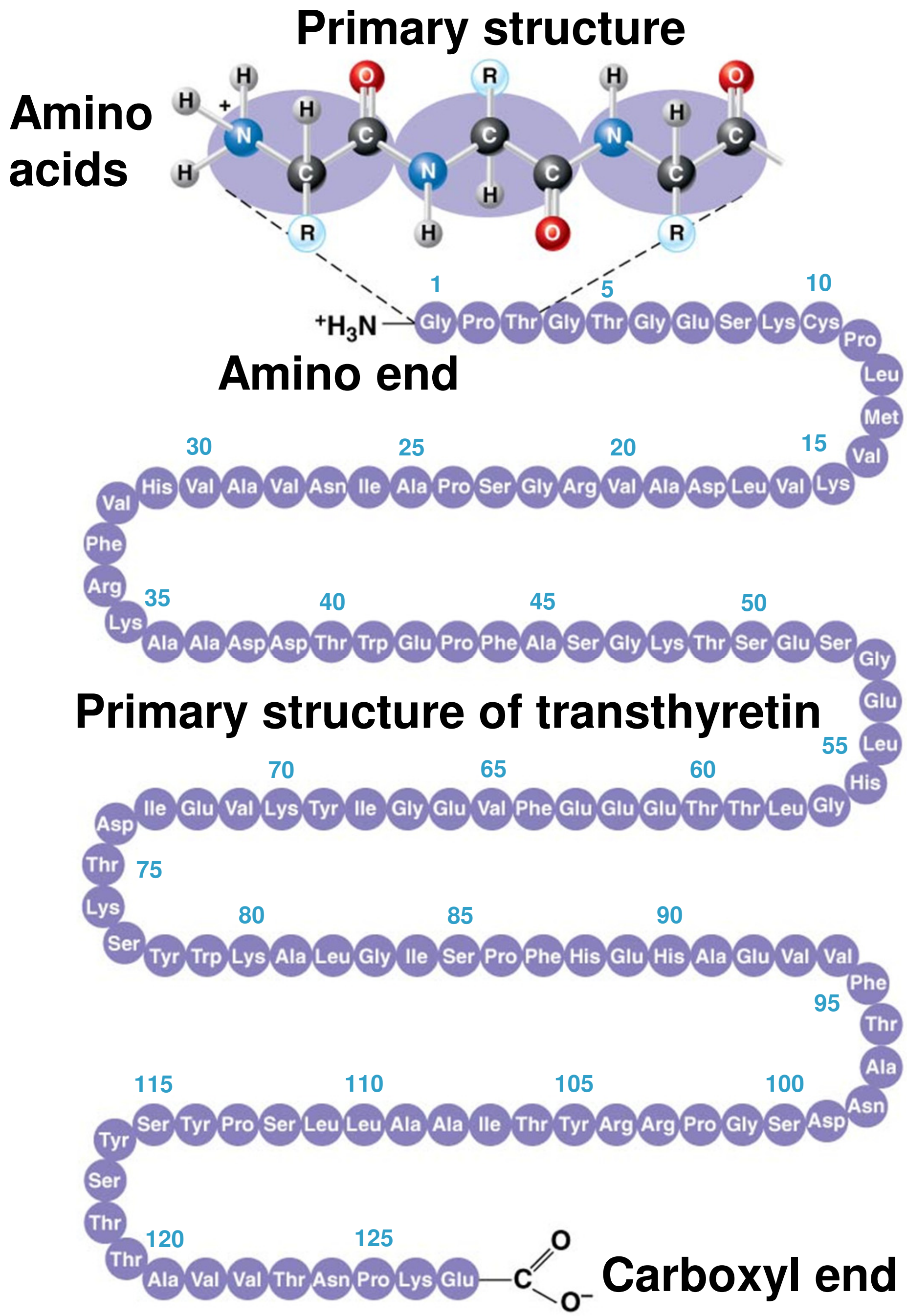


Animation: Tertiary Structure
Right click slide / Select play

Animation: Quaternary Structure

Right click slide / Select play

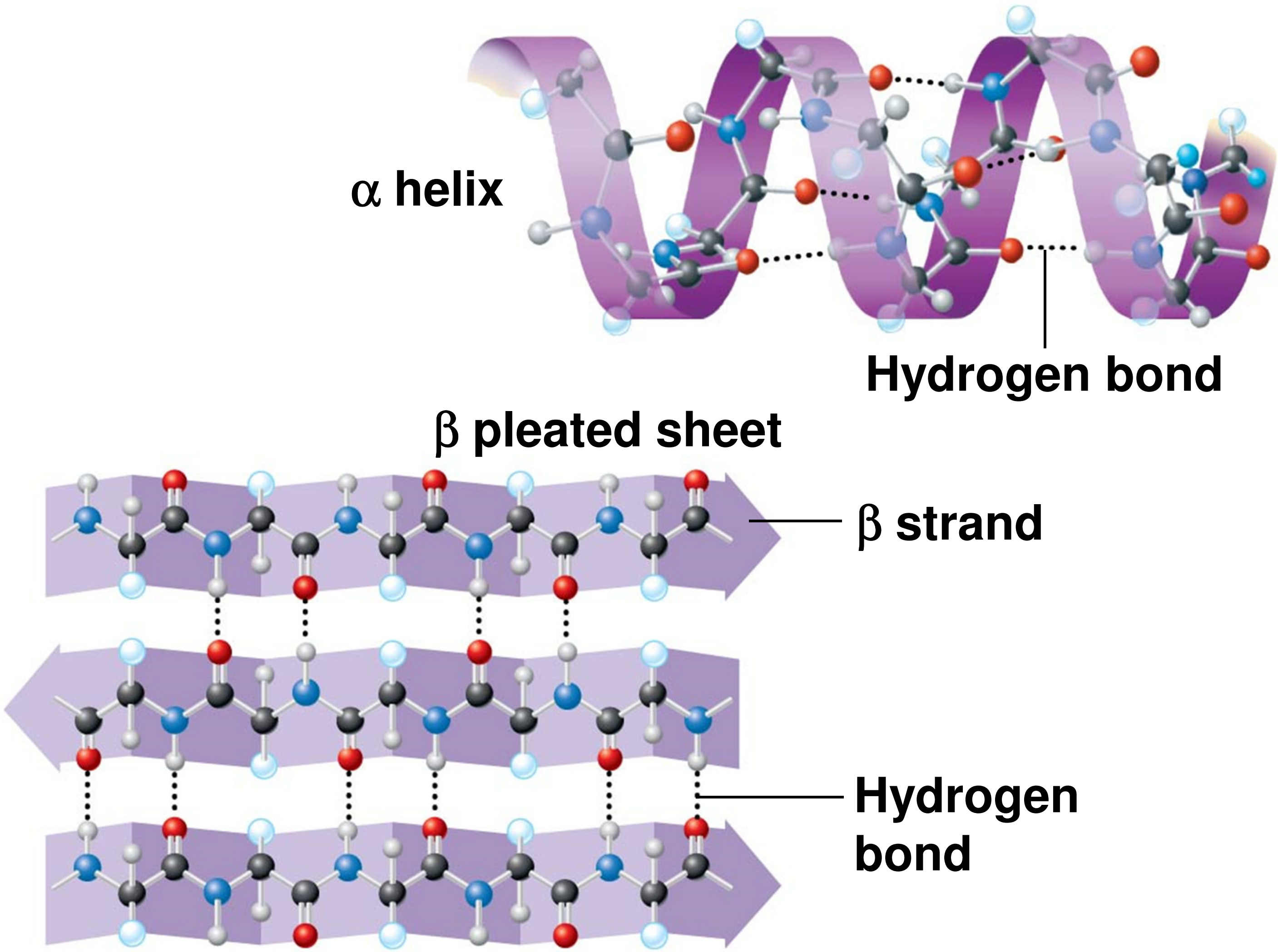
Figure 3.21a

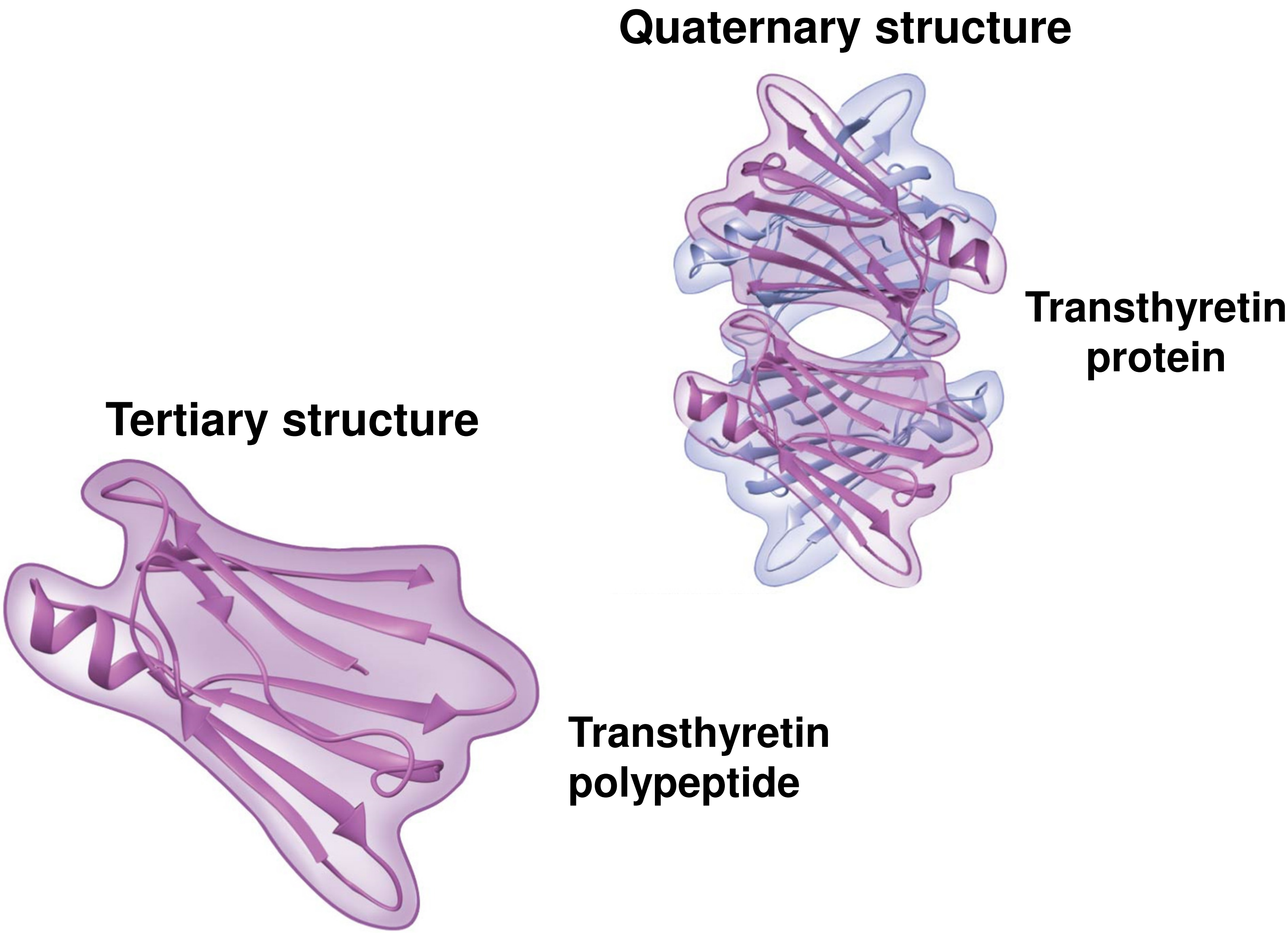


Primary structure
Amino acids
Amino end
Primary structure of transthyretin
Carboxyl end
^+H_3N
Gly Pro Thr Gly Thr Gly Glu Ser Lys Cys Pro Leu Met Val
His Val Ala Val Asn Ile Ala Pro Ser Gly Arg Val Ala Asp Leu Val Lys
Val Phe Arg Lys
Ala Ala Asp Asp Thr Trp Glu Pro Phe Ala Ser Gly Lys Thr Ser Glu Ser Gly Glu Leu His
Ile Glu Val Lys Tyr Ile Gly Glu Val Phe Glu Glu Glu Thr Thr Leu Gly
Asp Thr Lys Ser
Tyr Trp Lys Ala Leu Gly Ile Ser Pro Phe His Glu His Ala Glu Val Val Phe Thr Ala Asn
Ser Tyr Pro Ser Leu Leu Ala Ala Ile Thr Tyr Arg Arg Pro Gly Ser Asp
Tyr Ser Thr Thr
Ala Val Val Thr Asn Pro Lys Glu

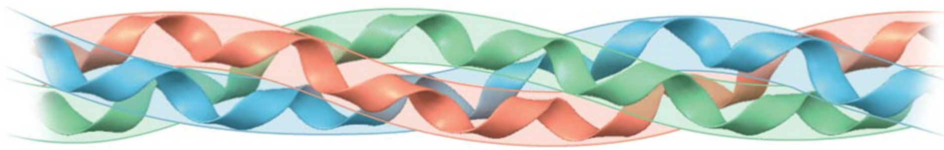
Figure 3.21ba

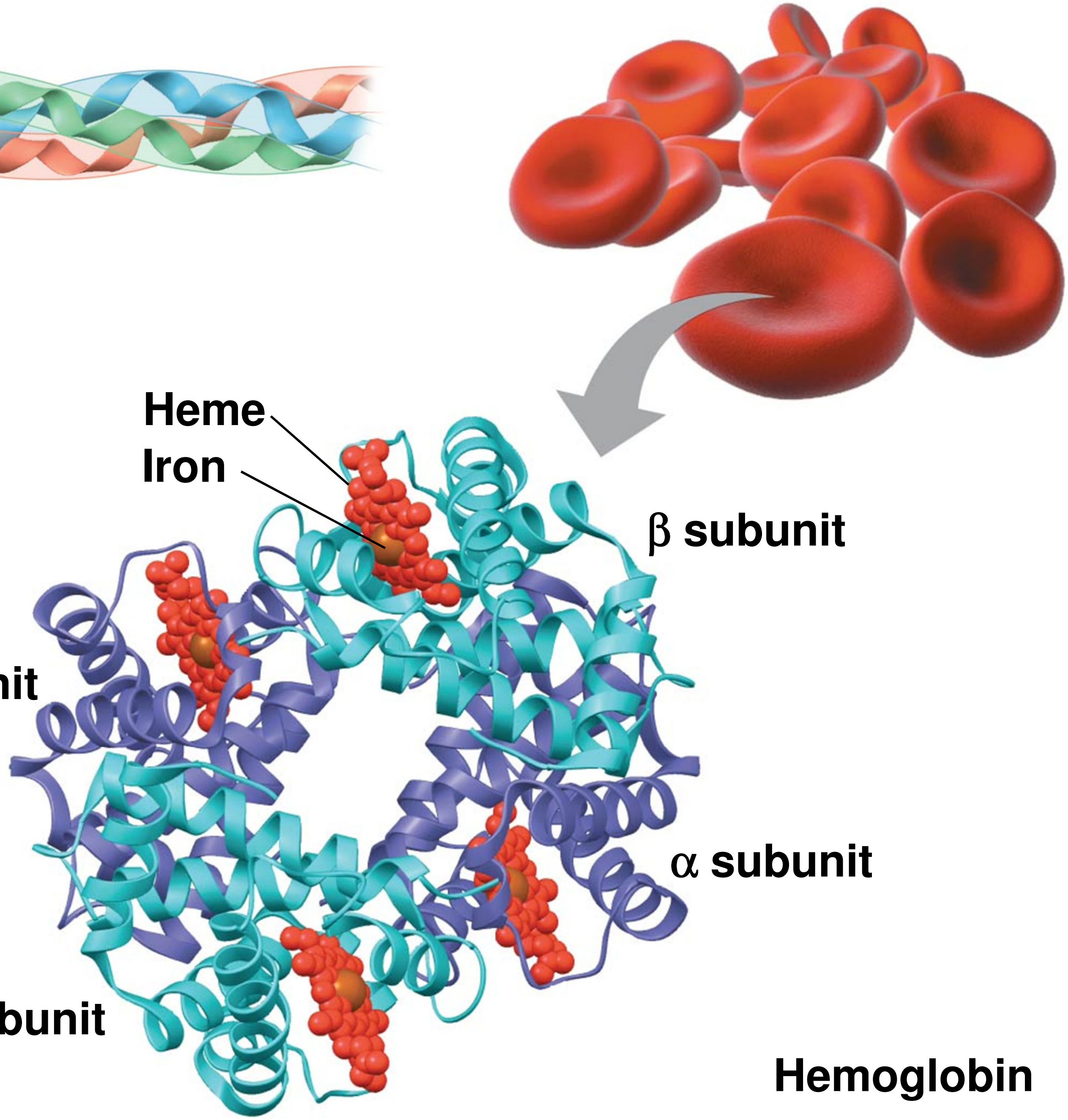
Secondary structure




Quaternary structure
Transthyretin protein
Tertiary structure
Transthyretin polypeptide

Collagen



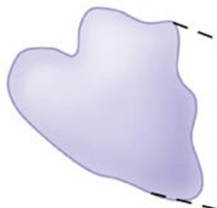
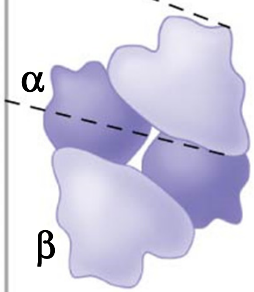
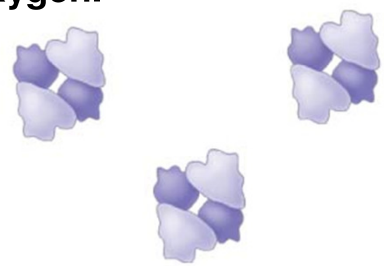
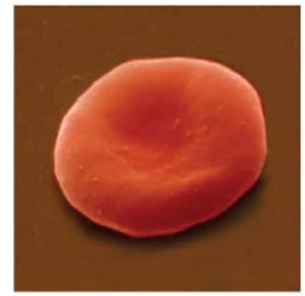
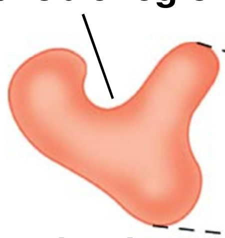
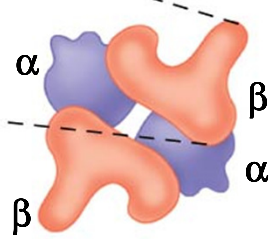
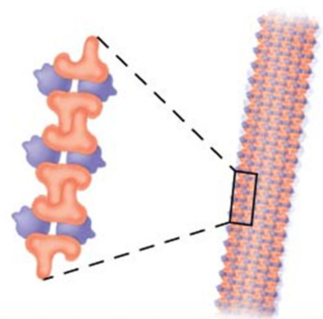


Hemoglobin

Sickle-Cell Disease: A Change in Primary Structure

- Primary structure is the sequence of amino acids on the polypeptide chain
- A slight change in primary structure can affect a protein's structure and ability to function
- **Sickle-cell disease**, an inherited blood disorder, results from a single amino acid substitution in the protein hemoglobin

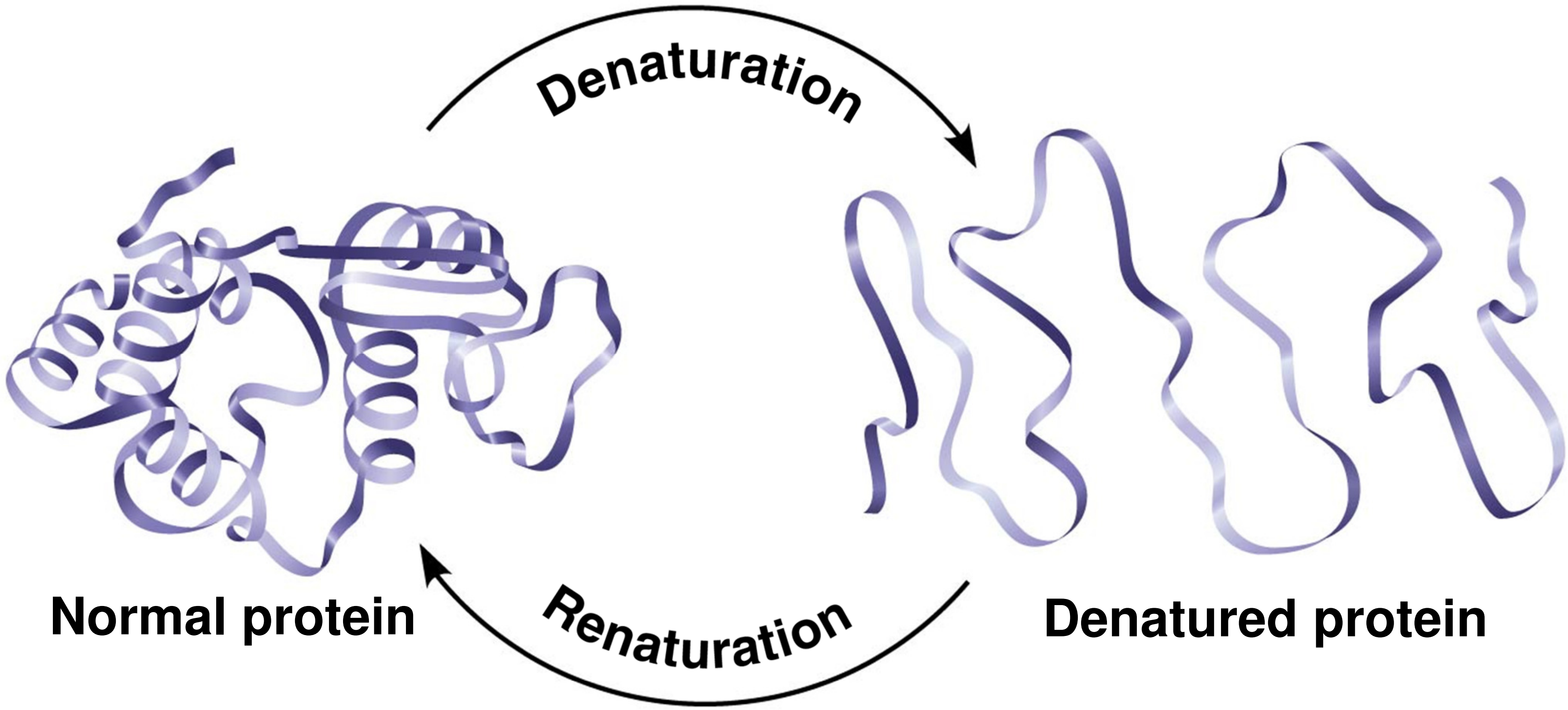
Figure 3.22

	Primary Structure	Secondary and Tertiary Structures	Quaternary Structure	Function	Red Blood Cell Shape
Normal	1 Val 2 His 3 Leu 4 Thr 5 Pro 6 Glu 7 Glu	 β subunit	Normal hemoglobin 	Molecules do not associate with one another; each carries oxygen. 	 5 μm
Sickle-cell	1 Val 2 His 3 Leu 4 Thr 5 Pro 6 Val 7 Glu	Exposed hydro-phobic region  β subunit	Sickle-cell hemoglobin 	Molecules crystallized into a fiber; capacity to carry oxygen is reduced. 	 5 μm

What Determines Protein Structure?

- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein’s native structure is called **denaturation**
- A denatured protein is biologically inactive
  - Shape affects function!

Figure 3.23-3


Denaturation
Normal protein
Renaturation
Denatured protein

Protein Folding in the Cell

- It is hard to predict a protein's structure from its primary structure
- Most proteins probably go through several intermediate structures on their way to their final, stable shape
- Scientists use **X-ray crystallography** to determine 3-D protein structure based on diffractions of an X-ray beam by atoms of the crystalized molecule

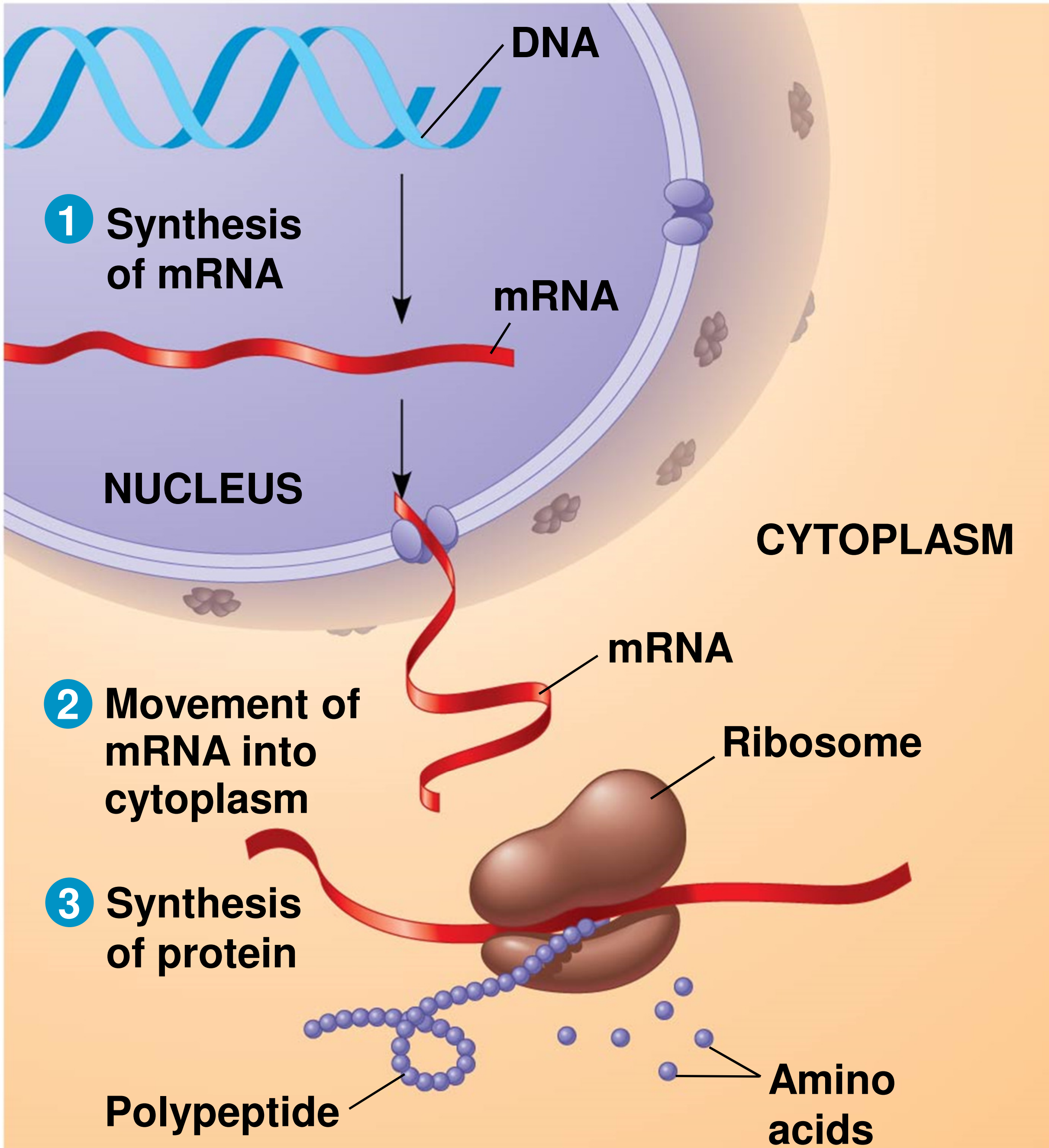
Concept 3.6: Nucleic acids store, transmit, and help express hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA, a **nucleic acid** made of monomers called nucleotides

The Roles of Nucleic Acids

- There are two types of nucleic acids
  - **Deoxyribonucleic acid (DNA)**
  - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication
- DNA directs synthesis of messenger RNA (mRNA) and, through mRNA, controls protein synthesis
  - Proteins are required to implement genetic programs
- Flow of genetic information:
  - DNA → RNA → Protein

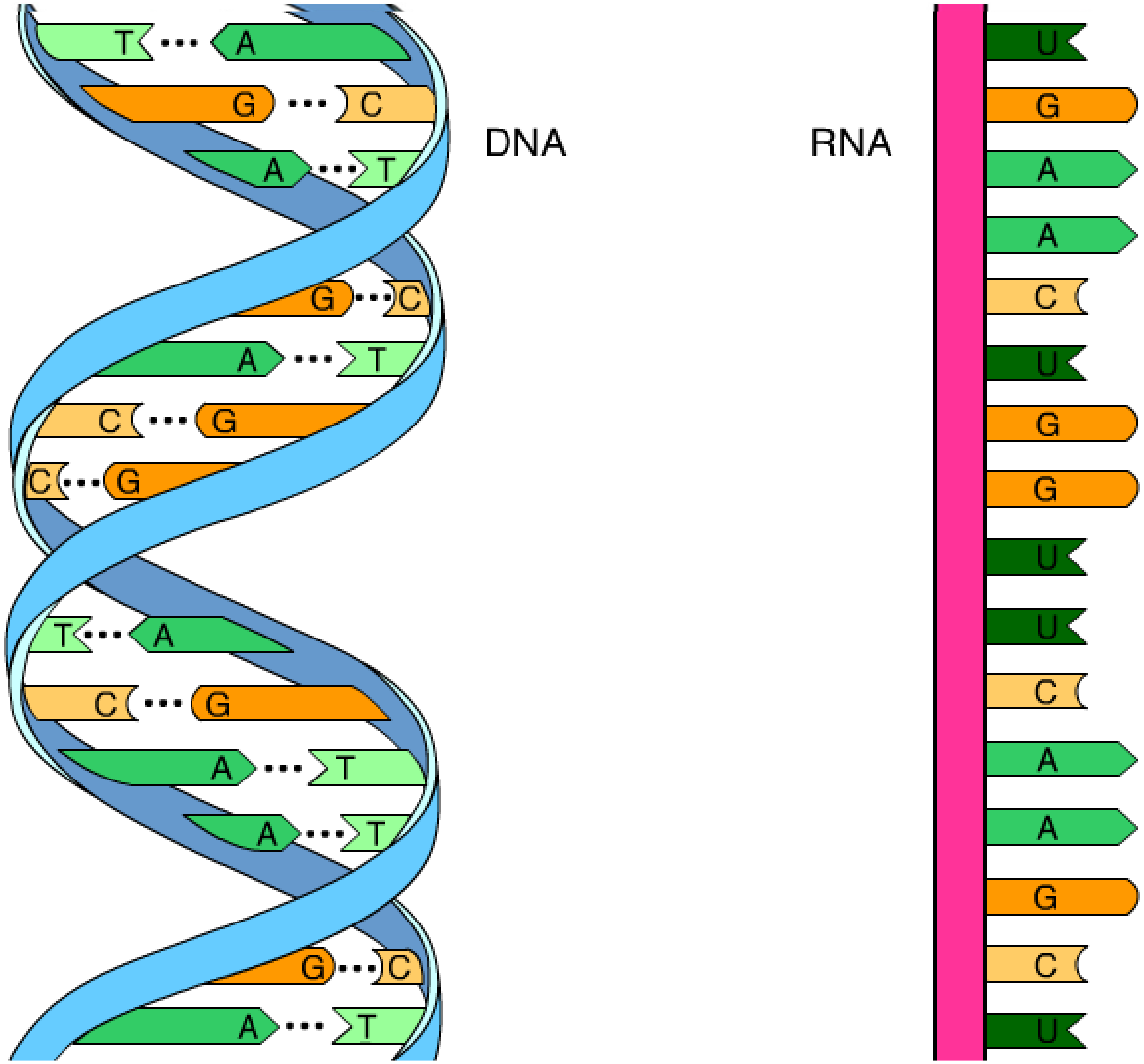
Figure 3.25-3



DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm
Ribosome
3 Synthesis of protein
Polypeptide
Amino acids

The Components of Nucleic Acids

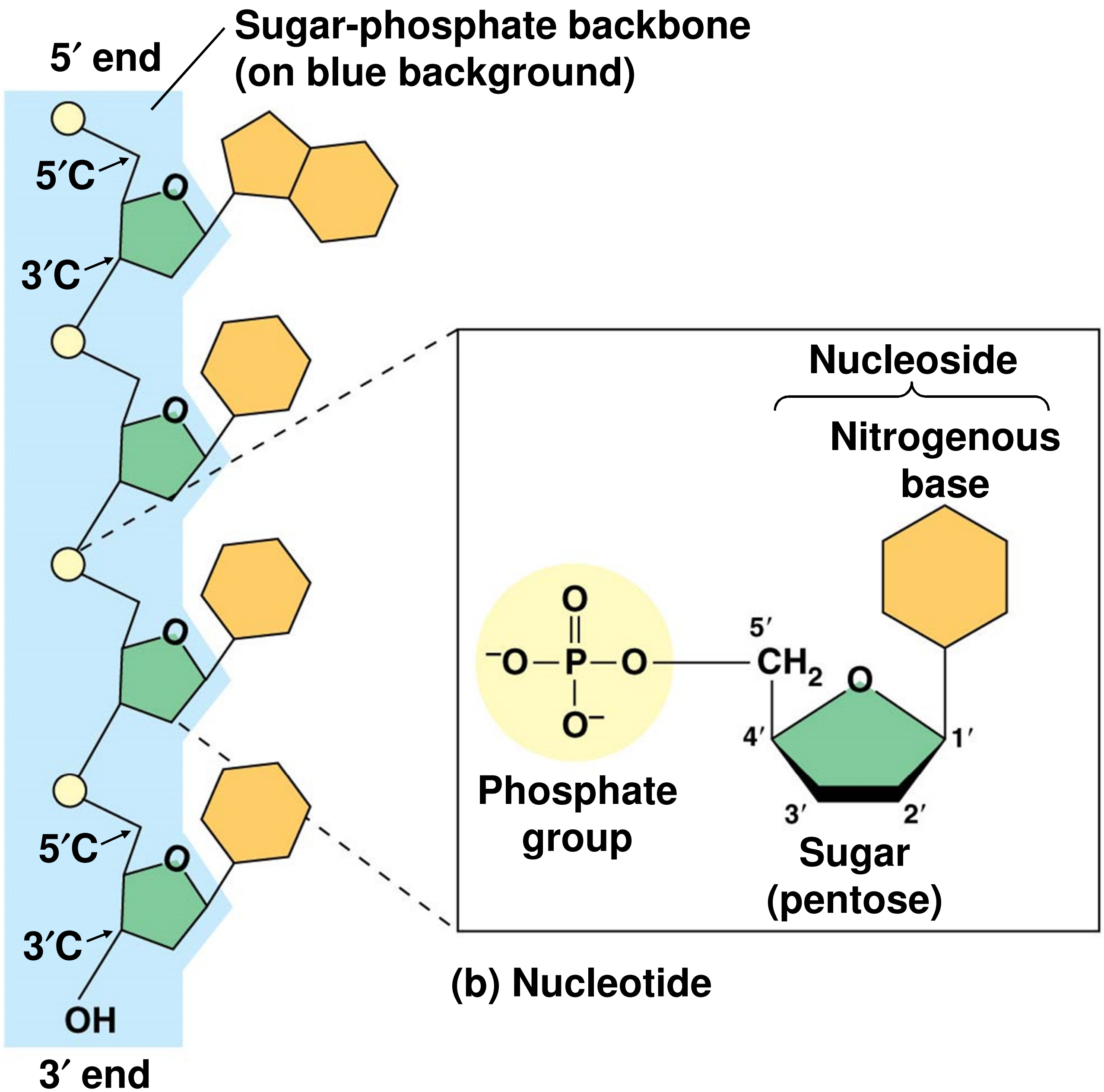
- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of
  - A nitrogenous base
  - A pentose sugar
  - One or more phosphate groups



Animation: DNA and RNA Structure

Right click slide / Select play

Figure 3.26a



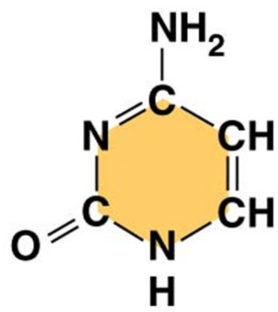
(b) Nucleotide

(a) Polynucleotide, or nucleic acid

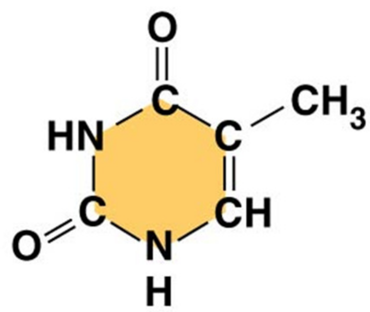
Figure 3.26c

Nitrogenous bases

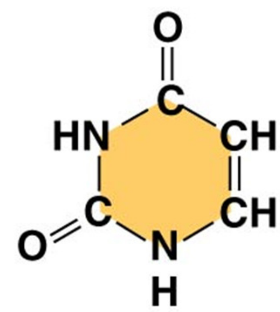
Pyrimidines



Cytosine (C)

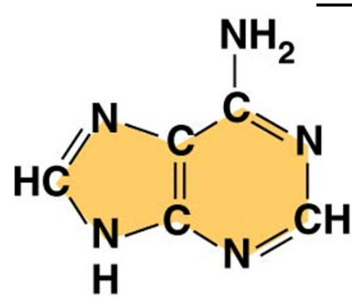


Thymine
(T, in DNA)

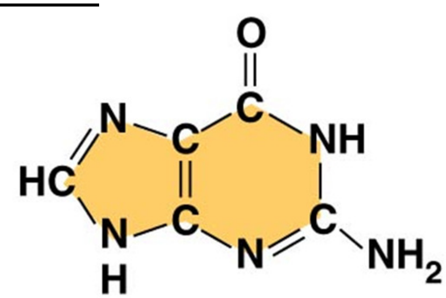


Uracil
(U, in RNA)

Purines

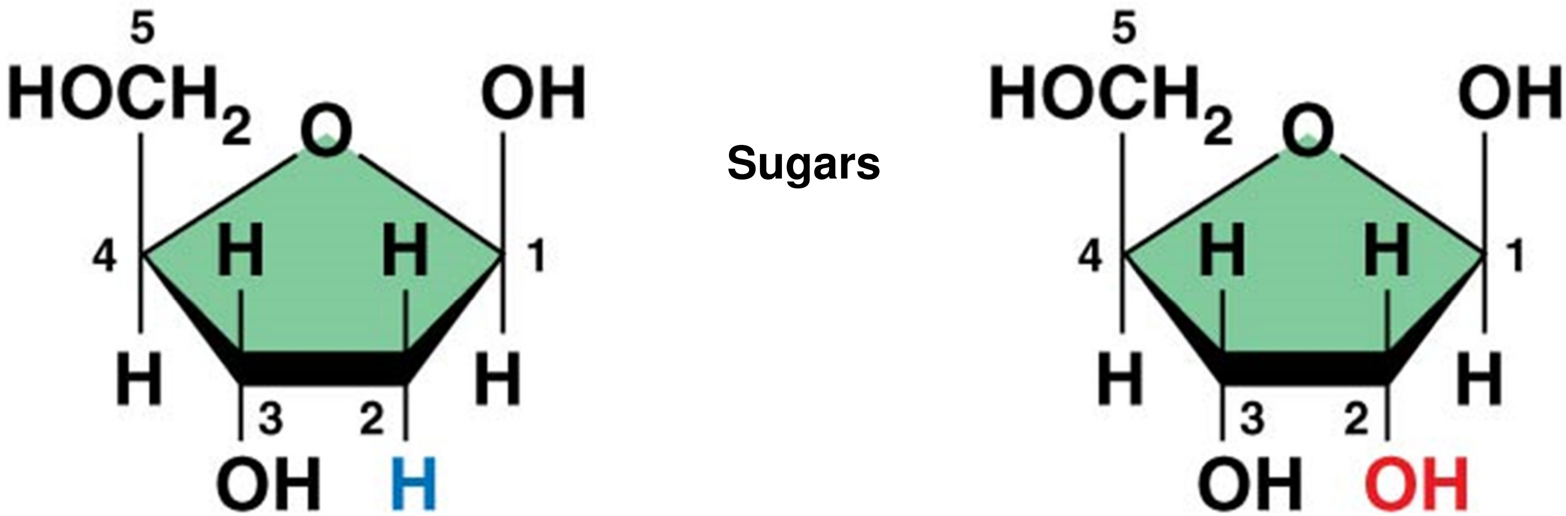


Adenine (A)



Guanine (G)

Figure 3.26d



Deoxyribose (in DNA)   Ribose (in RNA)

- Each nitrogenous base has one or two rings that include nitrogen atoms
    - ***Pyrimidines*** (single ring)
        - ***Cytosine*** (C)
        - ***Thymine*** (T)
        - ***Uracil*** (U)
    - ***Purines*** (2 ring structure)
        - ***Adenine*** (A)
        - ***Guanine*** (G)
- Thymine is found only in DNA
- Uracil is found only in RNA
- The rest are found in both DNA and RNA

- The sugar in DNA is **deoxyribose**
- The sugar in RNA is **ribose**
- A prime (′) is used to identify the carbon atoms in the ribose, such as the 2′ carbon or 5′ carbon

Nucleotide Polymers

- Adjacent nucleotides are joined by covalent bonds that form between the —OH group on the 3′ carbon of one nucleotide and the phosphate on the 5′ carbon of the next
  - Phosphodiester linkage
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene

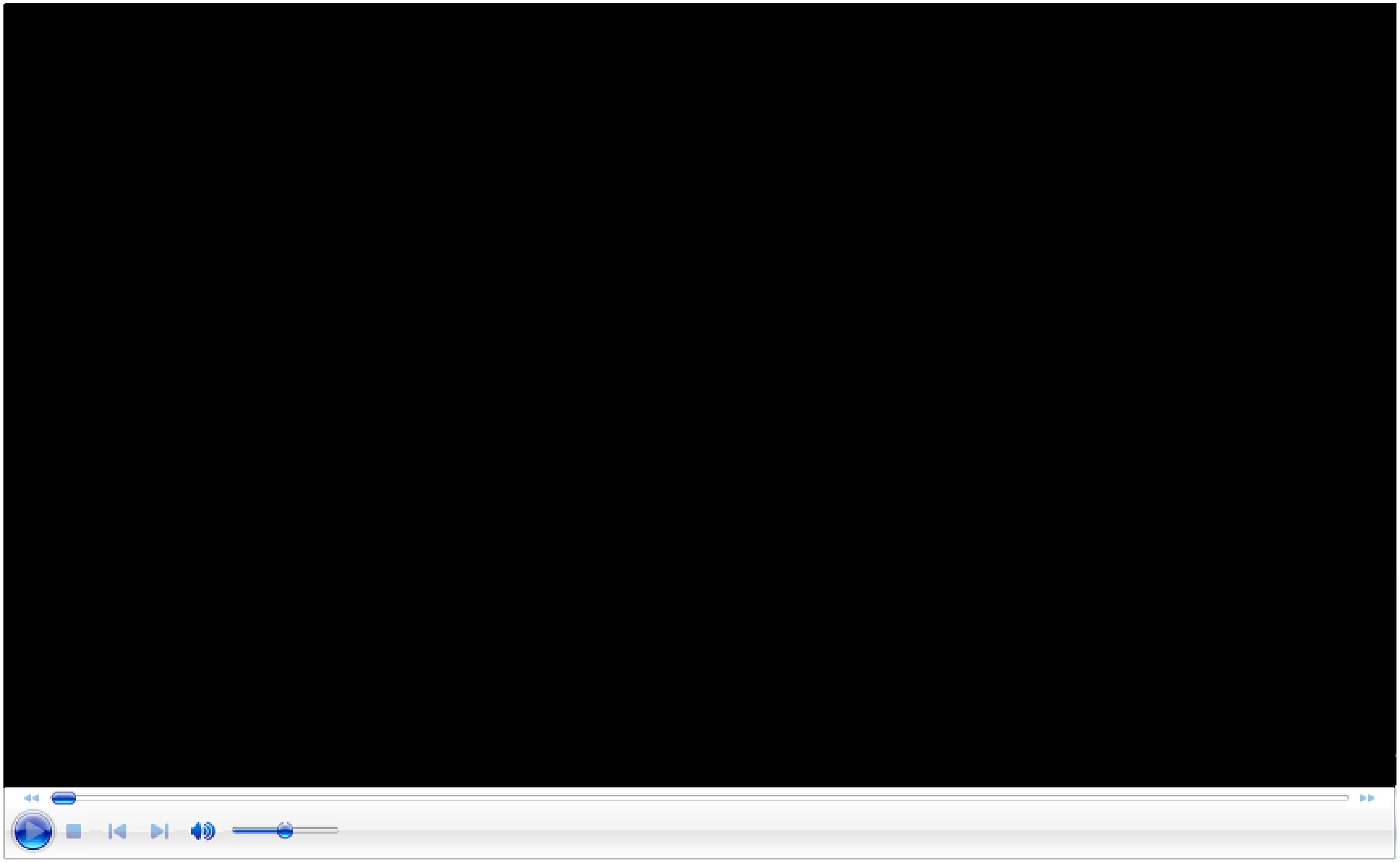
The Structures of DNA and RNA Molecules

- RNA molecules usually exist as single polypeptide chains
- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a **double helix**
- In the DNA double helix, the two backbones run in opposite 5′→ 3′ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes

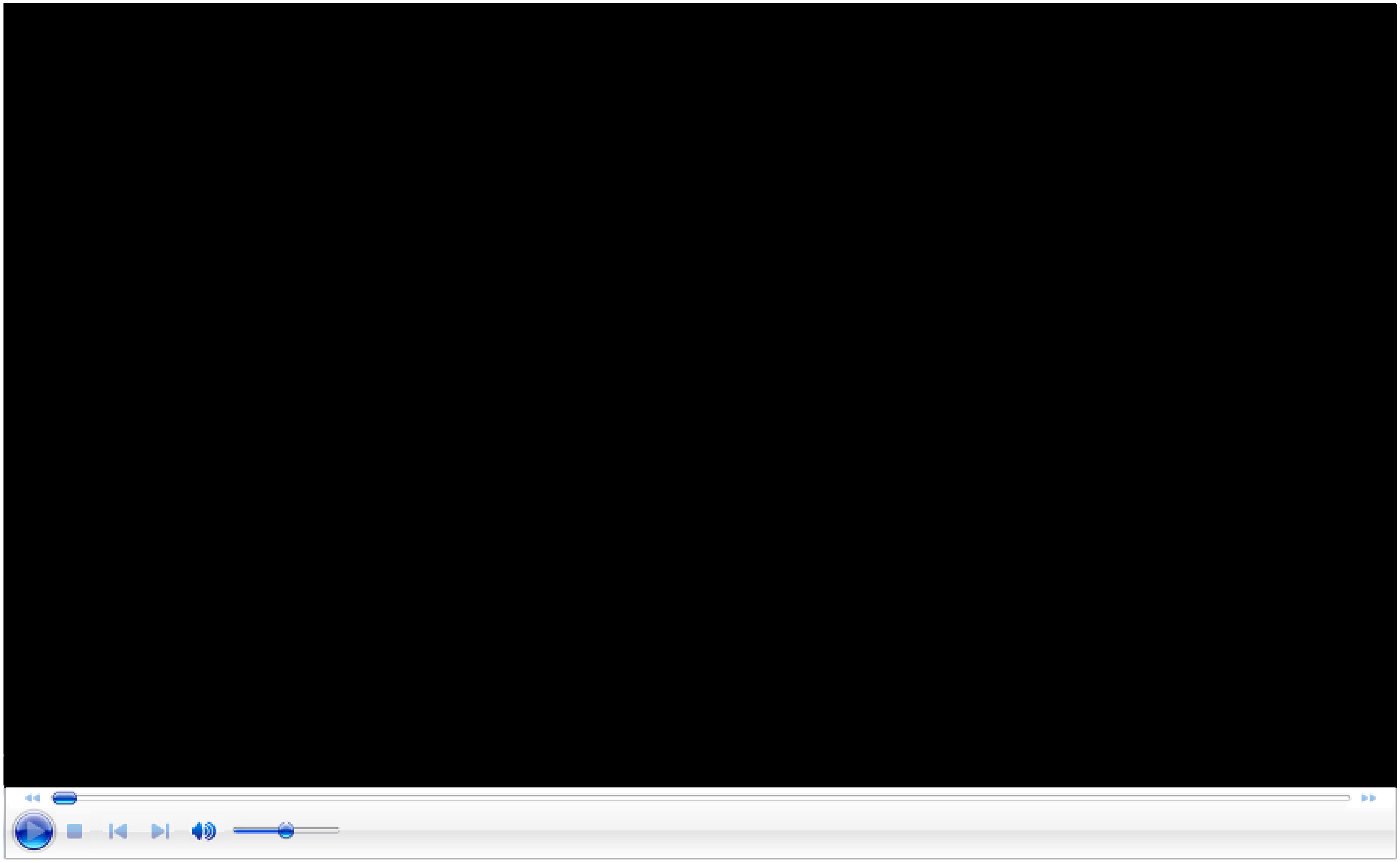
- The nitrogenous bases in DNA pair up and form hydrogen bonds:
  - Adenine (A) always pairs with thymine (T)
  - Guanine (G) always pairs with cytosine (C)
- This is called *complementary* base pairing
- Note: In RNA, thymine is replaced by uracil (U), so
  - A pairs with U

Animation: DNA Double Helix

Right click slide / Select play

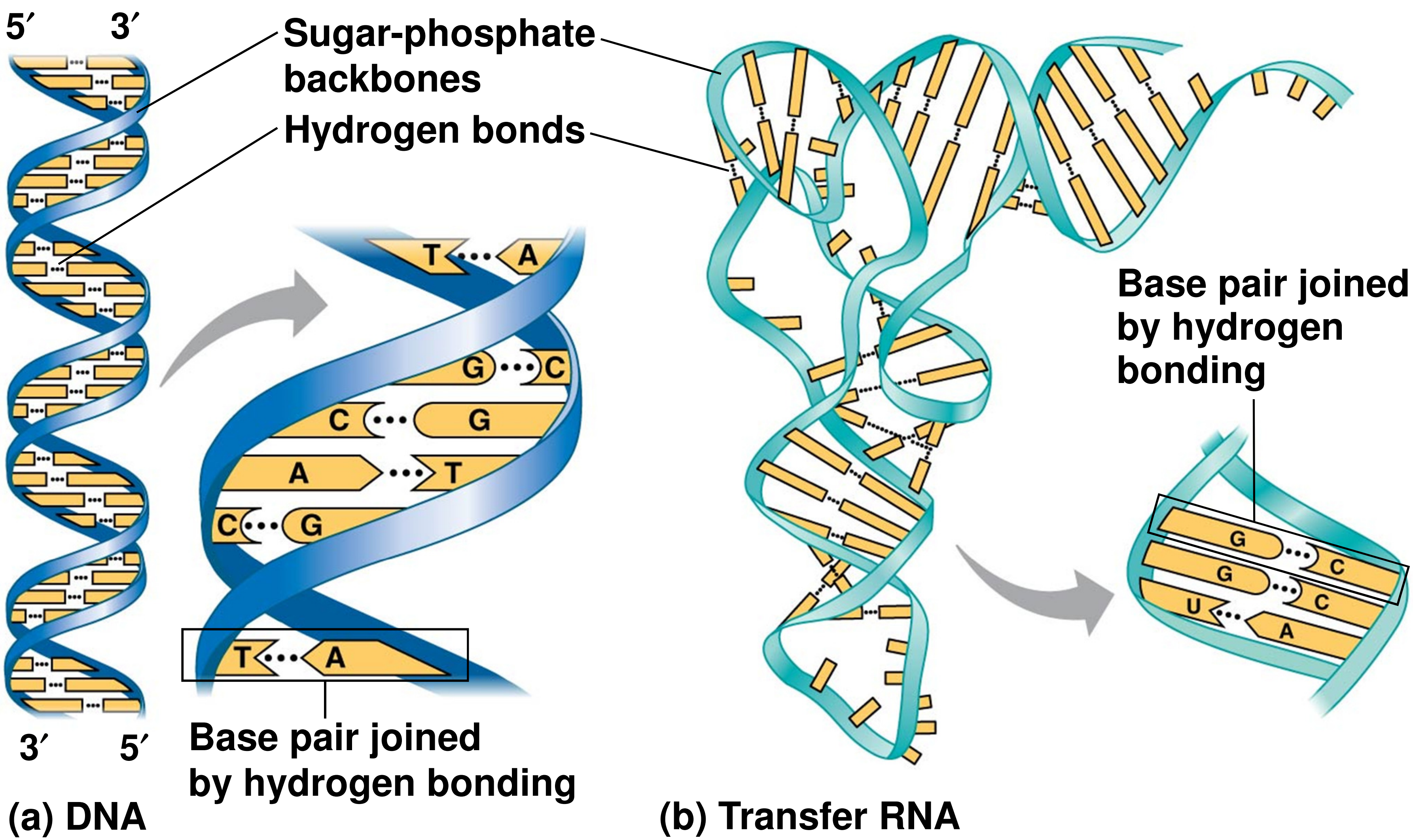


Video: DNA Stick Model



Video: DNA Surface Model

Figure 3.27


5′
3′
Sugar-phosphate backbones
Hydrogen bonds
T A
G C
C G
A T
C G
T A
3′
5′
Base pair joined by hydrogen bonding
(a) DNA
Base pair joined by hydrogen bonding
G C
G C
U A
(b) Transfer RNA

DNA and Proteins as Tape Measures of Evolution

- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than are more distantly related species
- Molecular biology can be used to assess evolutionary kinship